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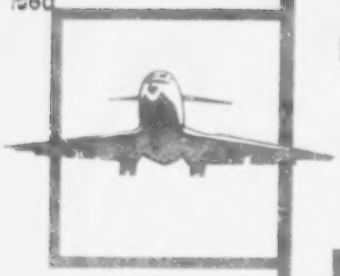

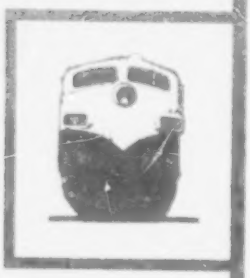

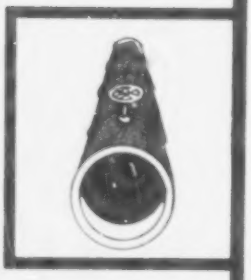

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MARINE ACCIDENT REPORT

EXPLOSION AND FIRE ON BOARD U.S. CHEMICAL TANKSHIP PUERTO RICAN IN THE PACIFIC OCEAN NEAR SAN FRANCISCO, CALIFORNIA OCTOBER 31, 1984

NTSB/MAR-86/05

UNITED STATES GOVERNMENT

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16. Abstract About 0324 on October 31, 1984, as the 660-foot-long U. S.-registered chemical tankship PUERTO RICAN was preparing to disembark a pilot about 8 miles west of the Golden Gate Bridge, San Francisco, California, an explosion occurred in the vicinity of the vessel's center void space No. 6. The main deck over the void and adjacent wing tanks was lifted up, blown forward, and landed inverted over center cargo tank Nos. 4 and 5 and their adjacent wing tanks. An intense fire erupted and burned out of control for several hours. A few hours after the explosion, the vessel was towed farther offshore in an effort to avoid polluting the coastline if the vessel sank. Several days later the vessel broke in two while in heavy seas, and the stern section sank. The bow section remained afloat and was later towed to a shipyard. The pilot and one crewmember were injured, and one crewmember is missing and presumed dead. The PUERTO RICAN was valued at $35 million.

The National Transportation Safety Board determines that the probable cause of the explosion on board the tankship PUERTO RICAN was the master's failure to require that center void space No. 6 be inspected for the presence of 50 percent caustic soda solution when he became aware of the possibility of a cargo leak from center port cargo tank No. 5. Flammable hydrogen gas produced by the reaction of the caustic soda solution with zinc in the epoxy paint and in the galvanized piping in center void space No. 6 was ignited by an undetermined source.

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

MARINE ACCIDENT REPORT

Adopted: April 18, 1986

EXPLOSION AND FIRE ON BOARD U.S. CHEMICAL TANKSHIP PUERTO RICAN IN THE PACIFIC OCEAN NEAR SAN FRANCISCO, CALIFORNIA OCTOBER 31, 1984

INTRODUCTION

This accident was investigated jointly by the National Transportation Safety Board and the United States Coast Guard. Public hearings were held in Oakland, California, from November 7 to November 19, 1984, from December 4 to December 13, 1984, and from January 8 to January 12, 1985. This report is based on the factual information developed by the investigation and on analysis made by the Safety Board. The Safety Board has considered all those facts in the investigative record that are pertinent to the Safety Board's statutory responsibility to determine the cause or probable cause of the accident and to make recommendations.

The Safety Board's analysis and recommendations are made independently of the Coast Guard. To inform the public of all Safety Board recommendations and responses, a summary of all recommendations and responses is published in the Federal Register.

SYNOPSIS

About 0324 on October 31, 1984, as the 660-foot-long U. S.-registered chemical tankship PUERTO RICAN was preparing to disembark a pilot about 8 miles west of the Golden Gate Bridge, San Francisco, California, an explosion occurred in the vicinity of the vessel's center void space No. 6. The main deck over the void and adjacent wing tanks was lifted up, blown forward, and landed inverted over center cargo tank Nos. 4 and 5 and their adjacent wing tanks. An intense fire erupted and burned out of control for several hours. A few hours after the explosion, the vessel was towed farther offshore in an effort to avoid polluting the coastline if the vessel sank. Several days later the vessel broke in two while in heavy seas, and the stern section sank. The bow section remained afloat and was later towed to a shipyard. The pilot and one crewmember were injured, and one crewmember is missing and presumed dead. The PUERTO RICAN was valued at $35 million.

The National Transportation Safety Board determines that the probable cause of the explosion on board the tankship PUERTO RICAN was the master's failure to require that center void space No. 6 be inspected for the presence of 50 percent caustic soda solution when he became aware of the possibility of a cargo leak from center port cargo tank No. 5. Flammable hydrogen gas produced by the reaction of the caustic soda solution with zinc in the epoxy paint and in the galvanized piping in center void space No. 6 was ignited by an undetermined source.

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INVESTIGATION

The Accident

On October 8, 1984, while at the PPG Industries, Inc. (PPG) terminal in Lake Charles, Louisiana, the U.S.-registered chemical tankship PUERTO RICAN (see figure 1), operated by Keystone Shipping Company (Keystone), completed loading a 50 percent caustic soda solution 1/ into cargo tank Nos. 1C, 4CP, 4CS, 5CP, 5CS, 7CP, and 7CS. (See figures 2 and 3.) An independent cargo surveyor gauged the tanks, and the ullages 2/ were witnessed by the second officer. At 2118 3/ on October 8, 1984, the PUERTO RICAN departed Lake Charles for San Pedro, California, via the Panama Canal. At 1030 on October 21, 1984, the PUERTO RICAN docked at the GATX terminal in San Pedro.

Shortly before noon on October 21, 1984, an independent cargo surveyor gauged the cargo tanks before discharging, and the 12-4 third officer recorded the ullages. None of the ullages recorded was compared at that time to the ullages taken at the loading port in Lake Charles. The crew decided from which tanks caustic soda would be pumped to transfer the scheduled amount of caustic soda to the GATX terminal, and at 1320 the discharge of caustic soda from the PUERTO RICAN was begun.

At 0400 on October 22, when the second officer assumed the watch, he was told by a GATX terminal employee that discharging of the scheduled amount of caustic soda would be completed about 0600. However, shortly before 0600 a terminal employee notified the second officer that about 3,000 more barrels of caustic soda were needed to complete the delivery. The second officer notified the chief officer of the request. For the first time, they compared the loading ullages recorded at Lake Charles with the predischarge ullages recorded at San Pedro. All of the loading and predischarge ullages were within acceptable industry tolerances except for those of tank No. 5CP. The loading ullage for tank No. 5CP was recorded as 13 feet 3 inches, while the predischarge ullage was recorded as 23 feet 1/2 inch. The ship's ullage tables indicate that an ullage difference of 9 feet 9 1/2 inches between 13 feet 3 inches and 23 feet 1/2 inch in tank No. 5CP is equivalent to 2,546 barrels. The surveyor checked the ullage on the receiving tank ashore and computed the amounts of cargo that had been discharged from the cargo tanks on the PUERTO RICAN. He concluded that the predischarge ullage of 23 feet 1/2 inch for tank No. 5CP was correct.

Concerned about the reported cargo shortage, the master, the chief officer, and the chief pumpman sounded all areas surrounding tank No. 5CP, with the exception of space No. 6CV, to determine if caustic soda had leaked from tank No. 5CP into those areas. The master testified that he had been told by a previous master that space No. 6CV had been sealed and inerted with nitrogen gas, so he looked for a sounding tube through which the space could be checked for liquid without opening a manhole cover and entering the space. Not finding any sounding tube for space No. 6CV, the master decided not to inspect the space. He decided to inspect tank No. 5CP later after the tank had been emptied of cargo and cleaned. Although the presence of caustic soda in space No. 6CV also could have been detected by activating the eductor system, 4/ the crew was not aware that the eductor system existed.

1/ Referred to hereinafter as caustic soda.

2/ Measurements of the distance between the top of the ullage opening in the top of the tank to the surface of the liquid in the tank.

3/ All times herein are local standard time based on a 24-hour clock, unless otherwise indicated.

4/ A system used to remove a liquid from an area.

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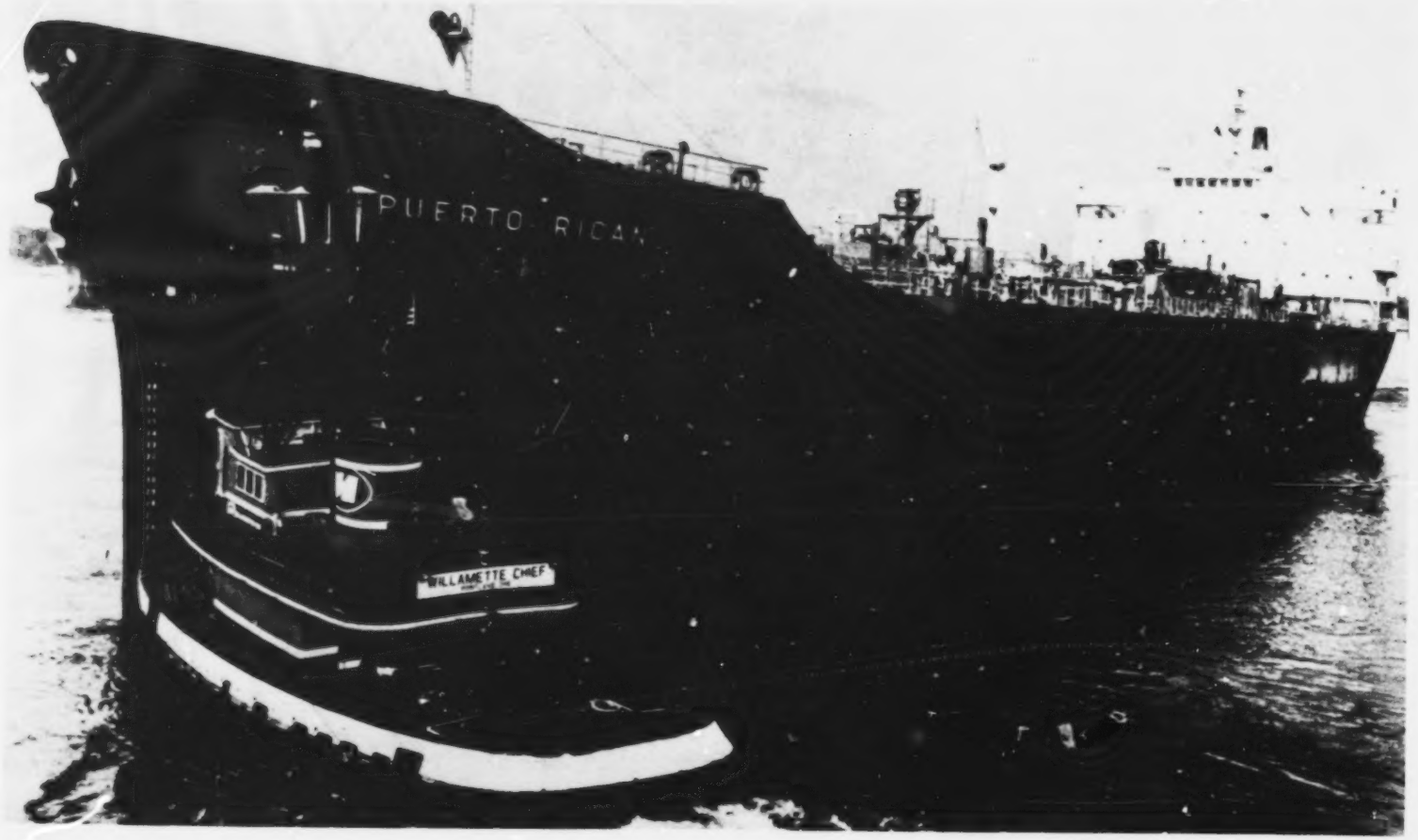

Figure 1.--View of the PUERTO RICAN on an earlier voyage.

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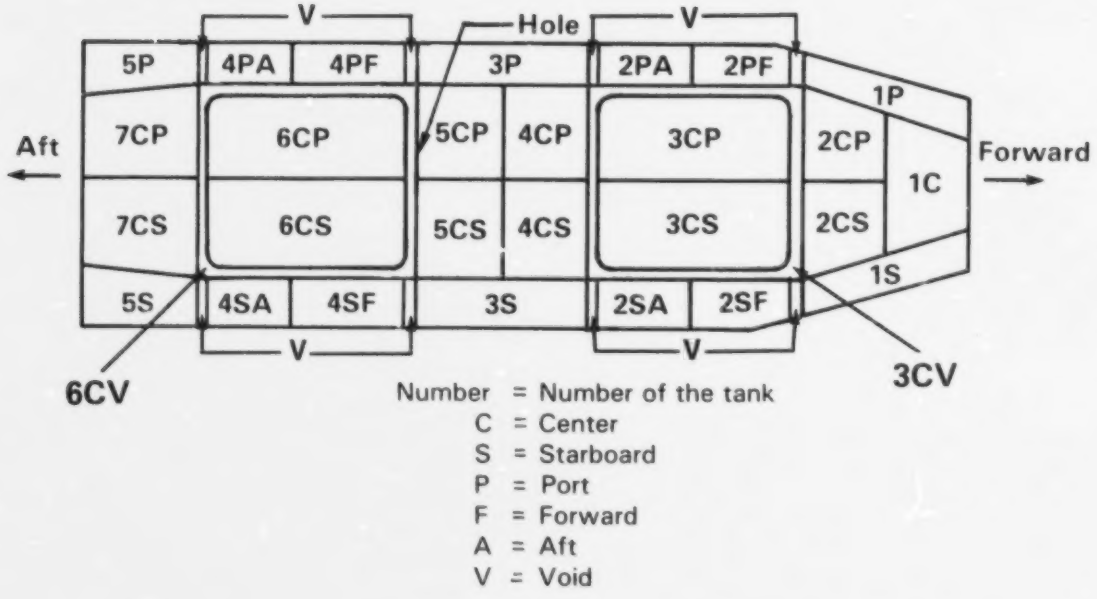

Figure 2.--Schematic plan of cargo tanks on the PUERTO RICAN.

The master obtained the cargo loading figures recorded by PPG when the caustic soda was loaded at Lake Charles. The PPG figures, which included an ullage of 13 feet 1/2 inch for tank No. 5CP, substantially matched the ship's loading figures. The master believed that the ship's discharging rate to the GATX terminal also supported the 13-foot ullage and concluded that the surveyor's predischarge ullage of 23 feet 1/2 inch was in error. The GATX terminal request for additional caustic soda was honored, but when discharging was completed and the chief officer signed the surveyor's ullage report, he added a statement that disputed the predischarge ullage of 23 feet 1/2 inch for tank No. 5CP. The master concluded that the ullage discrepancy was probably due to an error in reading the gauge or in recording the ullage. He testified that he believed the number "2" in the "23"-foot ullage was recorded incorrectly and that the ullage was actually 13 feet 1/2 inches. The surveyor signed the ship's record of ullages, but he added a notation that he disputed the predischarge ullage of 13 feet 3 inches for tank No. 5CP.

At 1230, the PUERTO RICAN moved to the Chevron Chemical berth, and the following morning moved to Wilmington Liquid Bulk Terminal, berth No. 187 where additional caustic soda was discharged. Both terminals are in the Los Angeles/Long Beach, California, area.

On October 24, the PUERTO RICAN sailed for Encinal Terminal in the San Francisco Bay. While at sea, the master and chief officer inspected tank No. 5CP using bright portable lights; they did not find any fractures or holes. On October 25, the vessel entered San Francisco Bay. At 1203 the vessel attempted to tie up at the Encinal Terminal but was unable to obtain line handlers due to a labor strike against Keystone. Shoreside picketing and picket boat strike activity occurred as the PUERTO RICAN shifted to several terminals in the bay area where the vessel loaded and discharged cargo between October 25 and October 30.

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TABLE

CARGO LOADING PLAN

WING TANKS	VOYAGE 238A	VOYAGE 238	VOYAGE 237A
1P	SLOPS	300 NEUTRAL OIL (S)	ALKANE 56 (C)
1S	SLOPS	300 NEUTRAL OIL (S)	ALKANE 56 (C)
2PF	PALE OIL 325 (C)	100 NEUTRAL OIL (E)	PARAFFIN WAX 143 (C)
2PA	PALE OIL 325 (C)	100 NEUTRAL OIL (E)	PARAFFIN WAX 143 (C)
2SF	EMPTY	100 NEUTRAL OIL (S)	PARAFFIN WAX 143 (C)
2SA	OLOA 247E (C)	100 NEUTRAL OIL (S)	PARAFFIN WAX 143 (C)
3P	ALKANE 56 (C)	PERCHLOROETHYLENE (P)	ALKANE 60 (C)
3S	ALKANE 60 (C)	1,1,1, TRICHLOROETHANE (P)	ALKANE 56 (C)
4PF	EMPTY	100 NEUTRAL OIL (S)	EMPTY
4PA	POLYBUTENE 24 (C)	100 NEUTRAL OIL (S)	POLYBUTENE 24 (C)
4SF	OLOA 246B (C)	100 NEUTRAL OIL (S)	EMPTY
4SA	OLOA 246B (C)	100 NEUTRAL OIL (S)	OLOA 247E (C)
5P	2033TR 300 (W)	100 NEUTRAL OIL (S)	EMPTY
5S	2033TR 300 (W)	100 NEUTRAL OIL (E)	EMPTY
CENTER TANKS			
1C	2033TR 300 (W)	CAUSTIC SODA (P)	PALE OIL 20 (C)
2CP	PROPYLENE TETRAMER (C)	CAUSTIC SODA (O)	ALKANE 60 (C)
2CS	PROPYLENE TETRAMER (C)	CAUSTIC SODA (O)	ALKANE 60 (C)
3CP & 3CS	EMPTY	EMPTY	EMPTY
4CP	EMPTY	CAUSTIC SODA (P)	EMPTY
4CS	EMPTY	CAUSTIC SODA (P)	EMPTY
5CP	ALKANE 60 (C)	CAUSTIC SODA (P)	EMPTY
5CS	ALKANE 56 (C)	CAUSTIC SODA (P)	EMPTY
6CP & 6 CS	EMPTY	EMPTY	EMPTY
7CP	CAUSTIC HEEL (P)	CAUSTIC SODA (P)	ALKANE 56 (C)
7CS	CAUSTIC HEEL (P)	CAUSTIC SODA (P)	ALKANE 56 (C)

MANUFACTURER:

C = CHEVRON U.S.A., Inc.
E = EXXON CORPORATION
O = OCCIDENTAL CHEMICAL CORPORATION
P = PPG INDUSTRIES
S = SUN OIL COMPANY
W = WITCO CHEMICAL CORPORATION

Voyage 237A - September 11 to September 30, 1984
Voyage 238 - September 30 to October 28, 1984
Voyage 238A - October 28, 1984 to the accident

Figure 3.--Cargo loading plan for last three voyages.

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On October 28, the PUERTO RICAN arrived at the Paktank Terminal in Richmond, California, where supervisory terminal personnel tied up the vessel. A cargo of Alkane-60, an aromatic hydrocarbon, was loaded into tank Nos. 3S and 5CP. (See figures 3 and 4.) Tank No. 5CP was loaded to an ullage of 8 feet 4 inches. Polybutene-24, a polymer of butene, from shore tank No. 111 was loaded into tank No. 4PA to an ullage of 4 feet 4 inches; it was loaded at a temperature of 176° F, and while aboard the ship it was continually heated by heating coils located in the bottom of the tank. On October 29, the PUERTO RICAN arrived at the GATX terminal in Richmond where the remainder of its caustic soda cargo was discharged.

On October 30, the vessel arrived at the Chevron Longwharf terminal in Richmond, its final stop in the San Francisco Bay. About 2100 on October 30, shortly before the PUERTO RICAN sailed, the master and the second officer were issued subpoenas to testify in court regarding the strike activity. After being relieved of their duties on board the PUERTO RICAN to give testimony, they left the vessel about 2300. The master was relieved by the chief officer. The chief officer was replaced by a new chief officer. A third officer moved up to second officer and was replaced by a new third officer. By 2300 on October 30, cargo loading was completed. The vessel was secured for sea, and at 0100 a San Francisco bar pilot boarded. At 0124 on October 31, the PUERTO RICAN sailed from Richmond for ports in the Gulf of Mexico with 29 crewmembers, including the pilot, on board. A picket boat followed the vessel until about 0300 when the vessel was in the vicinity of the Golden Gate Bridge.

As the PUERTO RICAN proceeded outbound via the main shipping channel, the crewmembers in the engineroom were performing their normal watchstanding duties. The crewmembers in the deck crew were performing their normal watchstanding duties, or other assigned duties, or were stowing mooring lines on the stern. The 16 other crewmembers were asleep in their rooms or otherwise not on duty. About 0320 the vessel left the main shipping channel at a speed of about 5 knots. Upon clearing the channel, the master changed course to 180° T to make a lee for the pilot to disembark onto the pilot boat SAN FRANCISCO. At 0320 he ordered the engine order telegraph to be put on "Dead Slow Ahead."

After the pilot completed his duties on the bridge, the third officer escorted him to the port side of the main deck, 120 feet forward of the deckhouse, above tank No. 4PF, where a pilot ladder was rigged and the standby able bodied seaman (AB) was waiting. The bottom two of the three chains spanning the 3-foot opening in the railing outboard of the kingpost were disconnected. The top chain was connected to the railing by a spring-loaded clip. No one on deck was smoking, and no flashlights were being used. The pilot's portable VHF transceiver on/off switch was in the off position. The pilot embarkation area was lighted by an explosion-proof floodlight located on the port bridge wing 120 feet aft of and 40 feet above the pilot embarkation area. A similar light on the forward side of the port kingpost approximately 20 feet above and 12 feet inboard of the pilot embarkation area was also on. No other lights in the area were on. The pilot was dressed in his normal work clothes, which included a nylon flotation jacket. The third officer was wearing work shoes, jean-type pants, a wool shirt, and a polyester wind breaker. No witnesses recalled what the standby AB was wearing.

After turning on the explosion-proof deck light on the port bridge wing, the master walked out on the port bridge wing to observe the pilot disembark. About 0324 as the master stepped through the wheelhouse door, an explosion occurred. He was shielded from the blast by the corner of the wheelhouse and the window on the bridge wing. He was knocked off balance by the pressure wave of the blast. As he turned his head

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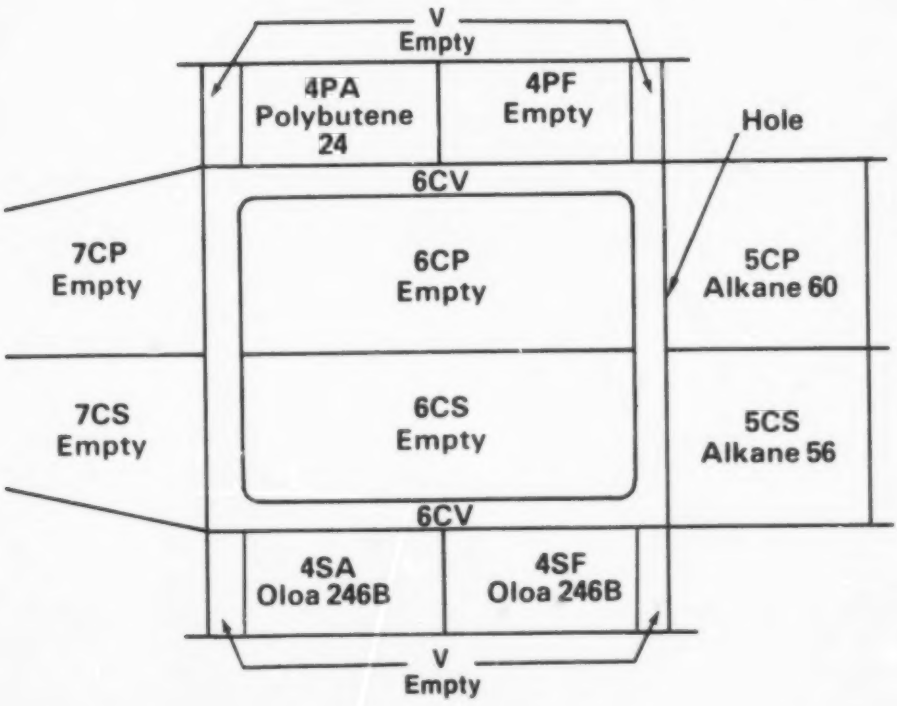

Figure 4.--Cargos in the tanks adjacent to space No. 6CV at the time of the accident.

forward, he saw a yellowish light and then bright orange flames extending across the vessel in the area of tank No. 6C. The flames were about 40 to 50 feet high, and appeared to be approximately level with the top of the deckhouse. Black smoke emanated from the flames. The PUERTO RICAN's approximate position was 37°45.8' N latitude and 122° 38.6' W longitude about 1/2 mile west of the San Francisco channel buoy No. "1." (See figures 5 and 6.)

The pilot and two crewmembers were blown into the water by the explosion. The pilot and one crewmember were later rescued. The other crewmember is missing and presumed dead. The vessel later broke in two and the stern section sank.

Injuries to Persons

Injuries	Crew
Fatal	1
Nonfatal	2
Minor/None	26
Total	29

Damage to Vessel

The PUERTO RICAN was valued at $35 million. The bow section was salvaged and sold for scrap. The cargo was valued at $20 million. Approximately 70 percent of the cargo was recovered.

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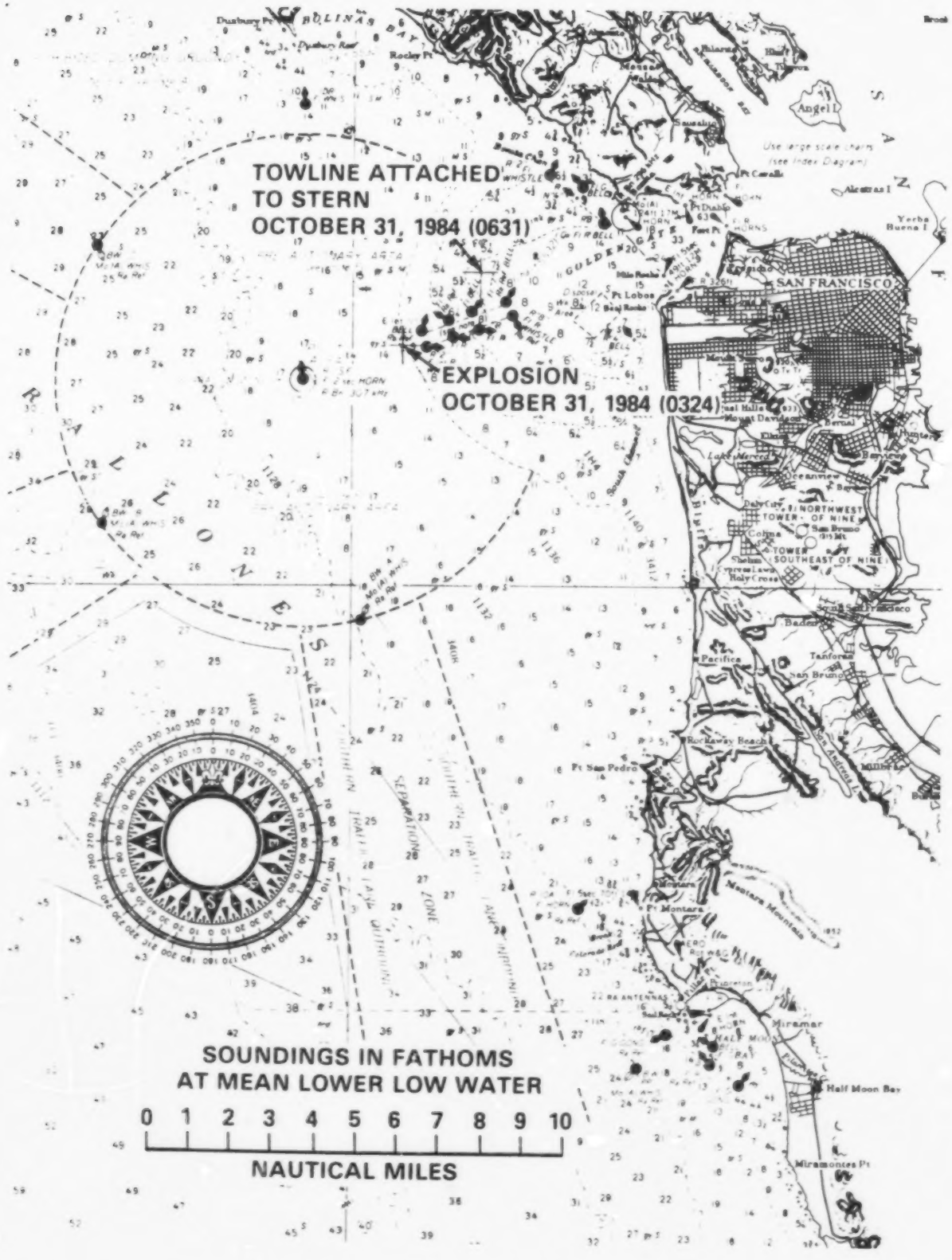

Figure 5.--Location of the PUERTO RICAN at the time of the explosion.

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Figure 6.--PUERTO RICAN after the explosion and before the stern section sank.

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Crew Information

The officers and crewmembers on board the PUERTO RICAN were properly licensed and documented as required by United States law. The vessel was properly manned in accordance with the vessel's Certificate of Inspection issued by the United States Coast Guard (USCG). (See appendix.)

Vessel Information

General.--The PUERTO RICAN, a U.S.-registered tankship of steel construction, was built by Bethlehem-Sparrows Point Shipyard, Inc., Sparrows Point, Maryland, in 1971. The PUERTO RICAN was classed by the American Bureau of Shipping (ABS). The ABS issued a load line certificate on December 10, 1981. The PUERTO RICAN had an overall length of 660 feet, a breadth of 90 feet, and a depth of 49 feet. The vessel admeasured 20,295 gross tons, 15,922 net tons, and had a deadweight of 34,684 tons. The vessel was propelled by a 15,000-shp steam turbine.

The vessel was owned and operated by West Coast Shipping Company of New York, New York, from the time it was built until April 6, 1982, when PPG Industries, Inc., of Pittsurgh, Pennsylvania, became the chartered owner and Keystone Shipping Company of Philadelphia, Pennsylvania, became its operator. In September 1983 the vessel was placed in lay-up status at Girard Point about 6 miles south of Philadelphia. During lay-up its USCG Certificate of Inspection expired. In May 1984 the vessel was towed to Pennsylvania Shipbuilding Company in Chester, Pennsylvania, where repairs and alterations were made and the USCG and the ABS performed inspections and surveys. A Certificate of Inspection, with two Certificate of Inspection Amendments and the Cargo Ship Safety Equipment Certificate were issued on June 22, 1984. On June 23, 1984, the PUERTO RICAN sailed from Chester to begin operation as a chemical tankship in the intercoastal trade between ports in the Gulf of Mexico and California.

Cargo tanks.--The PUERTO RICAN was designed to carry various cargos in special tanks. The center tanks, with the exception of center tank No. 1 (1C), were divided in half by a longitudinal bulkhead and were numbered from forward to aft and designated as either center port (CP) or center starboard (CS). The wing tanks were numbered from forward to aft and designated as port (P) or starboard (S), but their numbers were not the same as their adjacent center tanks. (See figure 2.) Where a numbered tank was divided into a forward and an after tank, the forward tank was designated by (F) and the after tank was designated by (A). The areas around tank Nos. 3C and 6C were designated center void (CV) spaces.

Tank Nos. 1C, 2C, 4C, 5C, and 7C were clad with stainless steel to enable them to carry caustic soda. The wing tanks and space Nos. 3CV and 6CV were covered with a coating of zinc-rich epoxy paint to prevent corrosion. Tank Nos. 3C and 6C were insulated with a layer of polyurethane about 3 inches thick and were designed to carry refrigerated cargo at atmospheric pressure with nitrogen in the surrounding voids. The vessel had not transported vinyl chloride monomer or butadiene inhibited, which tank Nos. 3C and 6C were designed to carry, since November 1979.

Tank Nos. 3C and 6C were approximately 102 feet long, 60 feet wide, and 39.5 feet high in the center. The top of tank Nos. 3C and 6C sloped downward slightly on both sides. Tank Nos. 3C and 6C each were divided by a longitudinal bulkhead.

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Space Nos. 3CV and 6CV were approximately 112.25 feet long, 65 feet wide, and 46.5 feet high. Space Nos. 3CV and 6CV contained structural members that supported tank Nos. 3C and 6C and antiflotation chocks designed to hold tank Nos. 3C and 6C from rising due to upward pressure which would occur if the spaces became flooded. Nonmetallic "Marinite 65" slats and sugar maple wood were placed between the bearing surfaces of the tanks and the tank support structures.

A galvanized steel piping system extended above, around, and under tank Nos. 3C and 6C. The piping system was used to inert space Nos. 3CV and 6CV with nitrogen gas when tank Nos. 3C and 6C were used to transport vinyl chloride monomer or butadiene inhibited. Space Nos. 3CV and 6CV were equipped with relief valves and flame screens located above the main deck. Each space had a 2-inch-diameter relief valve, which was set to relieve pressure at 2 psig. Each space also had three 6-inch-diameter relief valves, which were set to relieve pressure at 2.6, 2.8, and 3.0 psig, respectively.

The following pairs of wing tanks had separate filling and discharge piping as follows: Nos. 2PF and 2PA; 2SF and 2SA; 4PF and 4PA; and 4SF and 4SA. These tanks were approximately 53 feet long, 12 feet wide, and 46 feet high. Each wing tank had a 4-inch-diameter pressure relief valve which was set at 2 psig. The bulkhead between each of these pairs of tanks was fitted with a sluice valve, which when in the open position allows cargo to gravitate between the two tanks. The cargo pump for the after tank of each of the above pairs of wing tanks was used to discharge cargo from the forward tank.

Heating coils were installed in tank Nos. 2FF, 2PA, 2SF, 2SA, 4PF, 4PA, 4SF, and 4SA during the May/June 1984 shipyard period. The chief engineer testified that the cargo tank heating coil system had been difficult to operate because more steam than condensate was returning to the condensate tank in the engineroom. In October 1984, a cooler was installed on the condensate return line. The chief engineer said this revision caused condensate instead of steam to return to the condensate tank and made the system easier to operate but should not have affected the temperature of the saturated steam in the heating coils.

The chief engineer stated that the ship service steam was saturated steam at a pressure of 120 psig and a temperature of 350° F. A pressure relief valve was set to relieve at 140 psig. A high-pressure alarm was set at 150 psig. A high-temperature alarm was set at 370° F. The steam passed through a globe valve before it proceeded toward the first valve on deck, which when open would allow the steam to flow into the tank heating coils. The chief engineer stated that saturated steam at a maximum of 70 psig would have proceeded beyond the globe valve, which he operated. The temperature of saturated steam at 70 psig is 316° F. He stated that he did not hear the relief valve, the high-pressure alarm, or the high-temperature alarm activate at any time during the voyage.

Modifications to the tanks, such as the addition of the heating coils, required inspections and approval by the USCG. The USCG did not inspect the heating coils, and there was no evidence that it was notified about the heating coil installation from the master, owner, or agent as required by Federal regulations (46 CFR 31.10-20(d)). A representative hired by Keystone tested the heating coils at 200 psig of water pressure when the coils were installed. His records of the tests showed that any leaks or defects that he found were corrected. There was no evidence of a leak or failure of the heating coil system after the May/June 1984 shipyard period.

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Meteorological Information

According to the "Marine Safety Office San Francisco Bay On Scene Coordinators Report of the Tank Vessel PUERTO RICAN Explosion and Oil Pollution Incident," the wind at 0324 on October 31, 1984, was from the northwest at 10 knots. There was a light sea from the northwest and a low westerly swell. Visibility was 15 miles. Air temperature was approximately 55° F.

Medical and Pathological Information

The standby AB who was blown off the deck and into the water by the explosion is missing and presumed dead. The pilot and third officer were severely burned, and the pilot also sustained severe leg injuries. Both were hospitalized for several weeks.

Survival Aspects

About 2 seconds before the explosion while standing on the port side of the main deck with the pilot and the standby AB, the third officer heard a hissing sound behind him and toward the center of the ship. The explosion occurred before he could turn and determine the source of the sound. He estimated that the hissing sound originated about 40 or 50 feet away and sounded like a pressure relief valve discharging. At the same time, the pilot, who was standing next to the third officer, heard a click similar to the sound produced by the release of a spring-loaded clip followed by another sound that he described as a "whoosh." While hearing this sound, he observed a "bead" of light emanate from near the standby AB and travel diagonally across the deck toward the center of the deckhouse. The pilot also detected an acrid odor, strong enough to burn his nostrils, and felt the sensation that air was being pulled out of his lungs. The force of the explosion blew the pilot and third officer over the port side of the vessel into the water close to the pilot boat SAN FRANCISCO, which was about amidships and 100 feet to the left of the PUERTO RICAN. Immediately after the explosion, at 0325, a distress call was sent on VHF-FM radio channel 16 by the pilot boat SAN FRANCISCO. Hearing people shouting in the water, the pilot boat crew readied emergency man-overboard retrieval nets. By 0345, the pilot and third officer had been picked up from the water by the pilot boat net. The standby AB was not found.

A USCG C-130 aircraft was flying at an altitude of between 500 to 1,000 feet approximately 15 miles northwest of the PUERTO RICAN's location, and the three persons in the cockpit saw the explosion. The C-130 pilot said the initial fireball was approximately 400 to 500 feet high and the flames from an explosion that followed several seconds later were 1,000 to 1,200 feet high. The pilot flew his aircraft toward the location of the flames and arrived on scene about 7 minutes later.

Immediately after the explosion, the master of the PUERTO RICAN returned to the wheelhouse and sounded the general alarm. The second officer, who had been in his room preparing to come on watch, arrived on the bridge almost immediately after the explosion. The master ordered him to take charge of the deck. The second officer proceeded to ready the lifeboats for launching and to ready the firefighting equipment for use.

At 0332, the master transmitted a distress call on VHF-FM radio channel 16 and USCG Group San Francisco responded. Shortly thereafter, the master left the bridge and moved about the vessel surveying the damage, organizing firefighting efforts, and checking lifesaving equipment. The engine order telegraph remained on dead slow ahead, but the engineers stopped the propeller after the explosion.

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Soon after the explosion, the 8-12 third officer, after reporting to the bridge, tried to get the foam monitors operating on the main deck but was unsuccessful due to lack of water pressure. The master then ordered her to go to the bridge and man the radio. The long-range radio antennas were blown off the kingposts by the explosion. The long-range radio antennas consisted of a long wire that led from the flying bridge to the kingposts, which were located over the area where the explosion occurred. The VHF-FM radio on the bridge was the only radio used on the PUERTO RICAN during the disaster.

By 0333, the pilot of a USCG helicopter had been notified by the USCG Group San Francisco about the accident. At 0334 the pilot of the C-130 communicated on channel 16 with USCG Group San Francisco and assumed the search and rescue role of on-scene commander (OSC).

A few minutes after the explosion, the second officer ordered the boatswain to lower two lifeboats to the embarkation deck and to lay out the firehoses forward of the afterhouse. The master had not issued an abandon ship order, but the second officer subsequently ordered the lifeboats to be lowered to the water because he was concerned that the port list the PUERTO RICAN was developing would interfere with their ability to launch the lifeboats. The starboard lifeboat was lowered to the water first. The crewmember in the lifeboat operated the releasing gear. Since the sea painter had not been secured to the ship, the lifeboat drifted away from the ship. The port lifeboat was lowered to the water with two or three crewmembers aboard and released. Since a sea painter was secured to the lifeboat, it remained secured to the ship. The second officer was able to launch the 400-pound liferaft with the aid of the boatswain and the pumpman. The liferaft was installed so as to float free if the vessel sank. The crewmembers had difficulty lifting the liferaft over the 42-inch-high pipe rail at the edge of the deck on which the liferaft was stowed. After launching, the liferaft was inflated and led by its sea painter to the stern where four crewmembers boarded it.

Soon after 0345, the USCG helicopter was airborne and at 0358 the helicopter began its attempt to evacuate the third officer and the pilot from the pilot boat SAN FRANCISCO for medical treatment. About 0420, the pilot and the third officer were transferred from the pilot boat to the USCG helicopter, flown to the Presidio Army Base, San Francisco, California, and taken immediately to nearby Letterman Army Hospital for treatment of their injuries.

At 0409, the second officer transmitted the following message via VHF-FM radio to the USCG San Francisco: "This is the PUERTO RICAN. We are now leaving the bridge. We fear another explosion. All the crew is gathered on the stern. Most of the crew is on the stern." The C-130 (OSC) responded: "... take your survivors to the stern of your boat. We are directing vessels to the stern of your vessel."

About 0413, the operator of the towboat HARRY M came upon the drifting starboard lifeboat with one crewmember aboard and rescued the crewmember. At 0415, two USCG utility boats arrived on scene from San Francisco and attempted to approach the stern of the PUERTO RICAN to evacuate the survivors. Because of the motion of the vessel caused by the 4-foot swell from the west, the operators of the utility boats had difficulty trying to lay their boats against the stern of the PUERTO RICAN. Meanwhile, since an embarkation ladder was not available, some of the crew of the PUERTO RICAN slid down ropes to the lifeboat and liferaft at the stern of the vessel. One crewmember jumped from the afterdeck of the PUERTO RICAN into the liferaft, hitting a crewmember already in the liferaft.

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At 0429, the operator of the HARRY M offered and received permission from the OSC to pick up the remaining crewmembers from the stern of the PUERTO RICAN. The utility boats moved the lifeboat and liferaft, which were secured to the PUERTO RICAN's stern, so the HARRY M could approach. The three crewmembers in the lifeboat boarded the HARRY M, and four crewmembers in the liferaft boarded a utility boat. The HARRY M's flat bow enabled the towboat to lay against the PUERTO RICAN's stern. At this time the height of the towing knees 5/ on the towboat and the after maindeck of the PUERTO RICAN's stern were both about 10 feet above the waterline. This facilitated disembarkation as the crew stepped from the afterdeck onto the towboat's towing knees.

About 0440, the second officer gave the order to abandon ship. He went to the crewmembers who were manning the firehoses and the foam monitors, ordered them to leave and board the HARRY M, and then boarded the towboat himself. The foam monitors were left directed at the fire and operating.

About 0445, the chief engineer heard a person shout from the HARRY M that the PUERTO RICAN was going to sink. The person urged him to leave the vessel and told him that the master had already left the PUERTO RICAN. He went into the passageways of the deckhouse shouting for the master but received no answer. He went to the engineroom with the third assistant engineer and the engineman on watch and secured the fires in the boilers, the fuel oil sevice pumps, and the fans. After taking several logbooks and records, securing the lights, and leaving the fire pumps running, they went to the stern and boarded the HARRY M.

Shortly after 0500, as the pilot of the USCG helicopter was flying close to the ship and assessing the damage to the PUERTO RICAN, he noticed the port hull plating had started to tear and that the stern of the vessel was misaligned with the bow. (See figure 6). About 0520, he recommended to the OSC that all remaining crewmembers aboard the PUERTO RICAN be evacuated. No one answered the PUERTO RICAN's radio, so the pilot positioned his helicopter about 75 feet above the port side, forward of the deckhouse, used the helicopter's loud hailer, and announced three times: "This is the Coast Guard. We recommend you evacuate your vessel at this time." At 0526, the master left the PUERTO RICAN and boarded the towboat HARRY M. He was the last person to leave the vessel. The crew of the C-130 coordinated survivor counts to ensure that all persons were accounted for.

Fire

On the stern where most of the crew had gathered after the explosion, the master asked for and got several volunteers, instead of the crewmembers assigned firefighting duties by the ship's station bill, to lay out hoses and to fight the fire. From a fire station located aft of the deckhouse, three 2 1/2-inch-diameter, 50-foot-long fire hoses were used to reach forward of the deckhouse. Two 1 1/2-inch-diameter fire hoses from inside the deckhouse also were used to fight the fire. A white substance, later determined to be caustic soda, made some areas of the deck very slippery.

Several problems hindered the crew from getting water pressure to the fire stations and to the foam monitors. After the explosion, safety sensors caused the automatic fuel oil shutoff valve to close, extinguishing the fires in the boiler and causing a brief interruption in electric power until the emergency generator started. The first assistant

5/ Two vertical uprights even with the bow of the towboat that present a flat surface the towboat lays against the barge it is pushing.

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engineer quickly started the emergency electric fire pump, but he did not open the supply valve to the pump; several minutes later the chief engineer opened the valve. After putting the boiler back on line, the engineers energized the steam-driven primary fire pump. The water pressure failed to build because the explosion had severed an 8-inch-diameter deck fire main and foam line about 40 feet forward of the deckhouse. Since the fire main lines inside the deckhouse and on the main deck were interconnected, the water pressure was reduced throughout the entire fire main system. The pumpman was unable to blank off the ruptured fire main because the necessary proper-sized blanks were stowed forward of the fire and were not available. Several minutes later, the chief engineer and third assistant engineer isolated the forward section of the fire main system by manipulating valves in the engineroom. Estimates made by the crew of the amount of time from the explosion to the time of getting enough water pressure on the fire line to fight the fire ranged from 10 to 30 minutes.

Soon after the explosion, the boatswain and another crewmember tried unsuccessfully to operate the foam system. Later the chief engineer entered the smoke-filled foamroom, located in the forward part of the deckhouse and above tank No. 7CS, and noticed that the proportioning pumps 6/ were working but that the suction valves to the foam tanks were closed. The closed suction valves did not allow the foam to pass from the foam tanks to the foam monitors. After being driven from the foamroom by the heavy smoke several times, he was able to align the valves and place the foam system into operation. A few minutes earlier, the master had closed a block valve in the foam line just forward of the outside corner of the cargo control room located forward of the after deckhouse and above tank No. 7CP. This valve closure isolated the rupture in the foam line and prevented the foam from spilling onto the deck. The chief engineer estimated that the pressure in the foam system was between 40 and 50 psig. Although the system normally operated at approximately 175 psig, the reduced pressure was sufficient for the crew to apply foam to the fire about 40 to 45 minutes after the explosion, after which the flames decreased considerably. As an AB was operating a foam monitor, he noticed a solid object rise up in the center of the flames. This object was later identified as tank No. 6C.

At 0535, two additional utility boats arrived on scene and using their fire monitors applied cooling water to the hot spots on the side of the PUERTO RICAN's hull. Because of their limited amount of foam and the inability of their pumps and foam applicators to apply foam over the high sides of the PUERTO RICAN, the utility boats were not effective in extinguishing the fire.

At 0551, the USCG cutter POINT HEYER arrived and assumed OSC status. The fireboat CITY OF OAKLAND from Oakland, California, and two U.S. Navy tugs from Naval Station Treasure Island, San Francisco, began arriving on the scene at 0605, and prepared to lay a blanket of foam on the fire. The USCG Vessel Traffic Service (VTS) personnel in San Francisco observed on radar that the PUERTO RICAN had drifted to within 3.8 miles of Point Bonita. At 0631, the tug SANDY secured a line to the stern of the burning PUERTO RICAN so the vessel could be towed offshore to minimize pollution along the coastline in case the vessel broke apart. The CITY OF OAKLAND had to stop firefighting efforts at 0759 because of mechanical problems.

6/ Used to pump foam from foam storage tanks to the foam firefighting lines leading to the foam monitors.

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During the day, the USCG placed rescue and assistance teams aboard the PUERTO RICAN to verify that all personnel had abandoned ship, to check the extent of the damage, and to secure the ship's generators, ventilation system, and foam monitors. The foam monitors were secured so they would not break up the foam blanket laid by the CITY OF OAKLAND fireboat and the Navy tugs.

The OSC stated that by late evening no flames could be seen, but internal fires were on the PUERTO RICAN forward of the deckhouse. The Navy tugs remained throughout the evening and cooled the sides of the vessel by directing water streams from their fire monitors onto the PUERTO RICAN's side shell. They also periodically renewed the foam blanket when the fire was under control.

By 0230 on November 1, there was a significant decrease in the temperatures of the main deck and side shell plating. At daybreak, the towline was shifted from the stern to the bow of the PUERTO RICAN. At 0856, the USCG cutter CAPE CROSS assumed the OSC, and at 0930 an investigating team from the CAPE CROSS boarded the PUERTO RICAN. Each member of the team was wearing an oxygen breathing apparatus (OBA). The team went into the main deck area of the deckhouse. They found intense heat and smoke on the forward section of the main deck and on the deck above. The after section of the deckhouse was relatively unaffected by heat, but there was considerable smoke damage to the interior of the after section of the deckhouse. The fire team knocked out the portholes on the port and starboard side of the vessel to allow the wind to evacuate much of the trapped smoke. They searched through the forward area of the deckhouse for fire and hot spots. Firefighting efforts to extinguish small fires in the deckhouse were hampered because the intense heat trapped in these spaces quickly turned the firefighting water into steam. By 1200, fires in the deckhouse were under control. and the operators of the Navy tugs reported that no further hot spots were visible on the hull of the PUERTO RICAN.

Wreckage

About midnight on November 2, the PUERTO RICAN broke in the middle of space No. 6CV into two sections while located approximately 32 miles southwest of the Golden Gate Bridge. The stern section sank at 0120, and tank No. 6C floated free and was towed to Oakland, California. The bow section was towed to a graving dock in San Francisco on November 18. (See figure 7.)

A close examination of the bulkhead between tank No. 5CP and space No. 6CV revealed a small hole between two fillet welds. (See figure 8.) The hole was at the 16-foot 6-inch level (32-feet 1 1/2-inch ullage), measured from the bottom of the tank, and was obscured above, below, and in front by the horizontal stiffener plate and the gusset plate. Daylight entering tank No. 5CP facilitated locating the hole after the stern had broken away.

In tank No. 5CP and the other stainless steel-clad tanks were a number of small holes and cracks in the stainless steel cladding on the decks and bulkheads. The mild steel that these holes and cracks exposed was corroded and pitted. The areas surrounding the holes and cracks in the cladding were surrounded by rust stains. The rust stains on the shiny, metallic-textured, stainless steel cladding facilitated locating the otherwise difficult-to-locate holes and cracks in the cladding. Corrosion pits are common in tanks, such as tank No. 5CP, which have been carrying corrosive substances.

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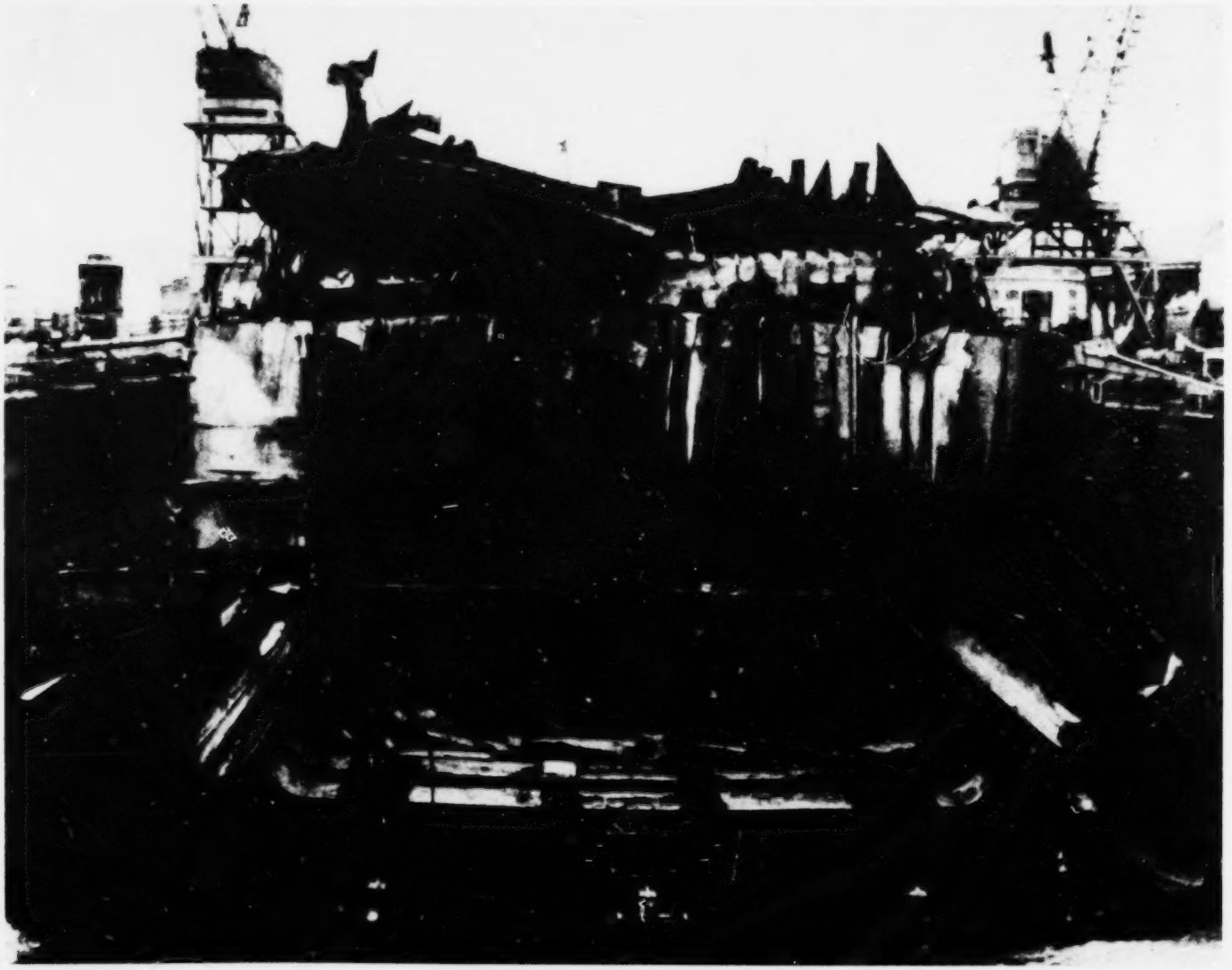

Figure 7.--View of forward half of space No. 6CV and cargo tank Nos. 4PF and 4SF, which remained attached to the forward section of the PUERTO RICAN.

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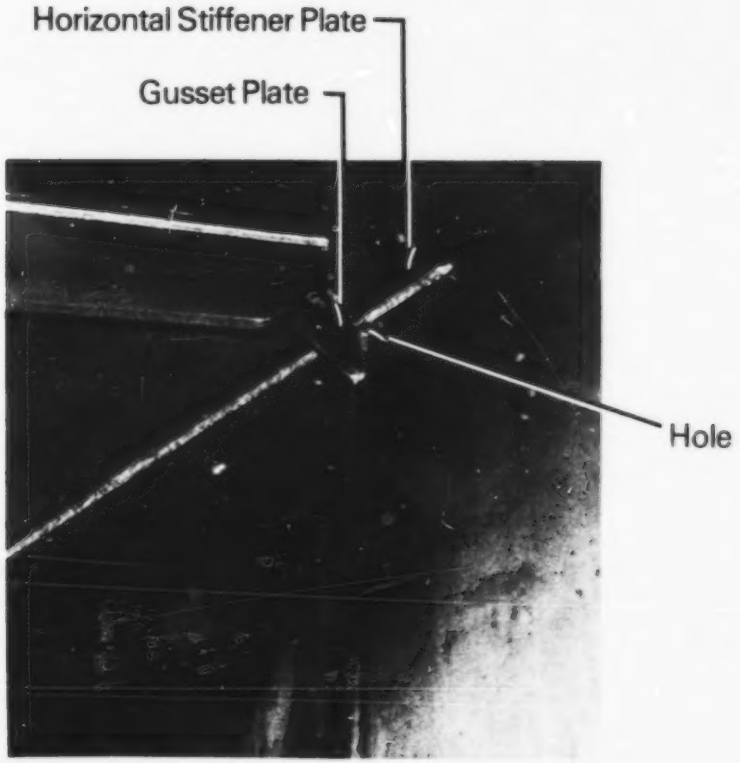

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Figure 8.--View of hole in the bulkhead between tank No. 5CP and space No.6CV as seen from tank No. 5CP.

The explosion caused the entire deck above space No. 6CV and the adjacent wing tanks to be lifted and thrown upside down on the deck immediately forward of space No. 6CV and the adjacent wing tanks. The transverse deck beams under the deck in space No. 6CV remained attached to the deck. The inverted deck from tank No. 6CV and the starboard wing tanks was concave toward the previous underside of the deck. The inverted deck from tank Nos. 4PF and 4PA was convex toward the previous underside of the deck. The deck over space No. 6CV had a circular tear around a dome that extended above the main deck surrounding the expansion trunk on tank No. 6C.

The following fractures occurred to release the main deck: the welds between the main deck and the longitudinal bulkheads between space No. 6CV and the adjacent port and starboard wing tanks; the vertical welds between the transverse deck beams in space No. 6CV and the longitudinal bulkheads; most of the deck plating extending from one side of the ship to the other along the forward and after transverse bulkheads of space No. 6CV; and the sheer strake plating 7/ just below the intersection with the main deck. The inverted deck was split along the weld that connected it to the longitudinal bulkhead between space No. 6CV and tank No. 4PA.

The transverse bulkhead that separated tank Nos. 5CP and 5CS from space No. 6CV was torn where it connected with the deck and with the port longitudinal bulkhead. The vertical and transverse supports on the transverse bulkhead were distorted. One side of a bracket supporting the nitrogen piping in the top of space No. 6CV was not bolted and was hanging loose.

The butterworth openings and expansion trunk covers on the inverted deck were closed, with the exception of the expansion trunk cover to tank No. 4PA. This cover was loose and the dogs were bent. There was considerable heat damage in the vicinity of the expansion trunk of tank No. 4PA. The cover for the expansion trunk on tank No. 4SA was blown off, and the deck to which this expansion trunk was attached sank with the stern section of the vessel.

The top and the port, starboard, and aft sides of tank No. 6C (see figure 9) were buckled inward. The forward side sustained minimal structural damage. The 3-inch-thick polyurethane insulation on the lower approximately 3 feet of the tank sides and the bottom showed no fire damage. The polyurethane insulation covering the rest of the tank was either completely burned away or badly charred. The outer shell of the tank had several fractures, most of which were less than 1 foot long. There was a black oily mixture in the bottom of the tank.

A black oily substance was found on the previous underside of the inverted deck. Most of the main deck forward of the inverted deck was clean and dry and did not have the black oily substance found on the inverted deck.

Tests and Research

As part of the investigation conducted by the Safety Board and the USCG, specific tests and research were performed. Some tests were performed by Failure Analysis Associates (FaAA), an engineering and metallurgical consulting firm. Other tests were performed by Chevron Research Company.

7/ Uppermost row of side plating connected to the deck.

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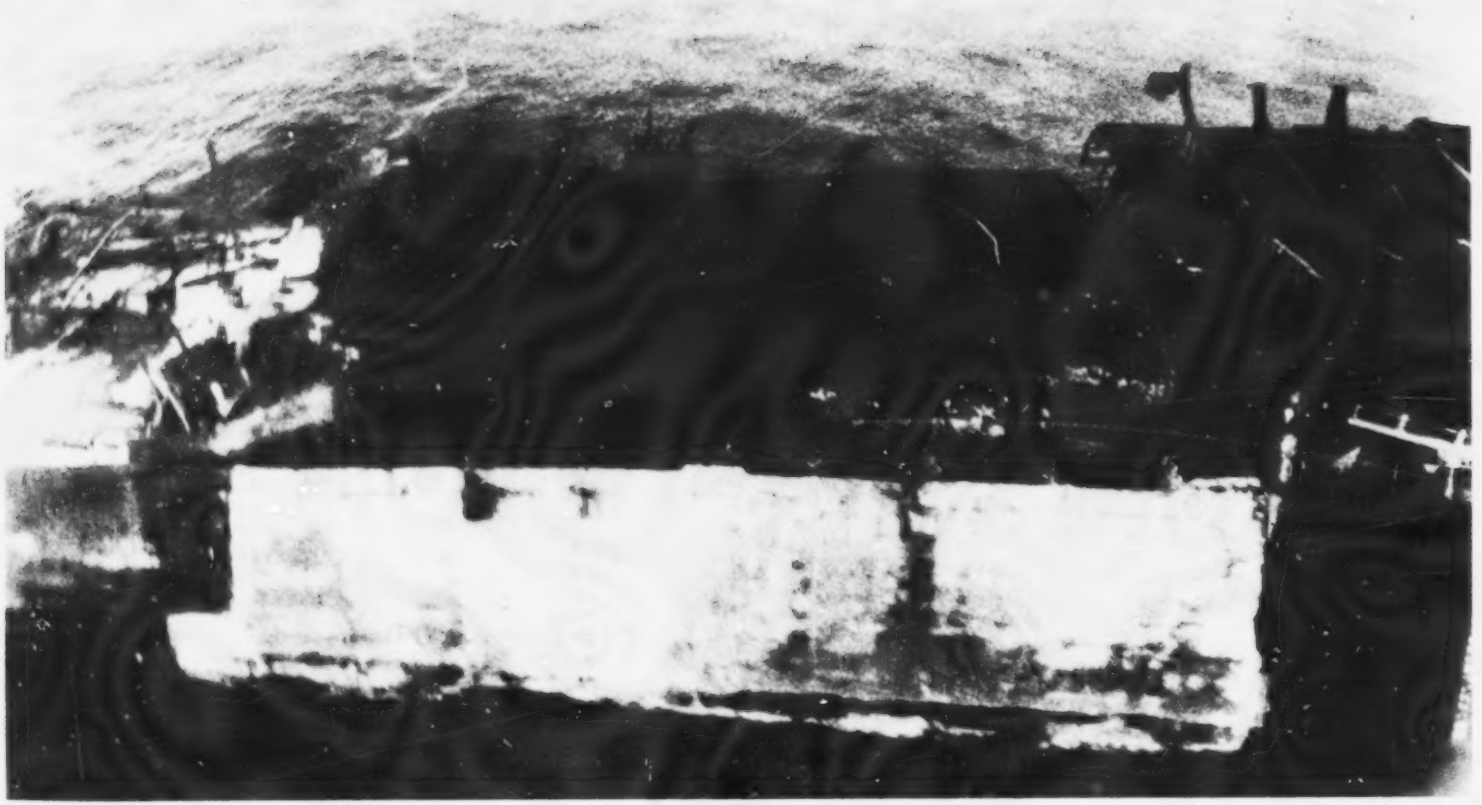

Figure 9.--View of tank No. 6C.

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Hole in the bulkhead separating tank No. 5CP and space No. 6CV.--The bulkhead separating tank No. 5CP and space No. 6CV was constructed of 7/16-inch-thick mild steel with a stainless steel cladding from 0.08 to 0.09 inch thick on the tank No. 5CP side. Several sections were cut from the area around the hole in the bulkhead. A section at the lower edge of the hole and to port of the gusset plate showed that the stainless steel cladding at the edge of the hole previously had been melted, apparently leaving the mild steel exposed. No evidence of weld material was found. A stainless steel lip extended beyond the edge of the hole in the corroded mild steel. (See figures 10 and 11.)

The opening through the stainless steel cladding was an irregular ellipse with a horizontal diameter of about 1.4 inches and a vertical diameter of about 0.5 inch. In the mild steel, the hole widened at first, with the mild steel bulkhead undercut behind the stainless steel cladding by about 0.2 inch. The hole then narrowed toward the opening on the space No. 6CV side, which was approximately elliptical with a vertical diameter of 0.6 inch and a horizontal diameter of 0.4 inch. The mild steel surface of the hole had a thick layer of corrosion products. No deformation of the plate surrounding the hole, as might be caused by an explosion, was detected.

The stainless steel fillet welds near the hole had been made in several passes and penetrated deeply into the mild steel. The welds had a matte, etched appearance and were less bright than the more recent repair welds in tank No. 5CP. There was no evidence of repairs near the hole.

Hole in vacuum breaker riser from space No. 6CV.-- The vacuum breaker 8/ riser for space No. 6CV was a 2.5-inch-diameter mild steel pipe about 2.5 feet long. Inspection of the vessel showed that the pipe had a hole about 2 inches by 2 inches, which was in a location with limited access and was obscured by an adjacent plate and pipe. The riser pipe was heavily corroded on the outside. It had been painted, but there were areas of thick corrosion deposits under the paint. The edges of the hole were thinned as a result of corrosion and were bent outward at some locations. There was a thin layer of rust inside the pipe. There were no visible signs of soot or other combustion deposits on the rust layer. By contrast, there were thick deposits of burned material on the underside of the deck where the riser pipe entered space No. 6CV. There was a thin, dark-gray deposit on the painted surface of the adjacent pipe that partially obscured the hole.

Pilot vent stack for pressure relief valves from space No. 6CV.--The pilot vent stack was normally connected to four pressure relief valves by flexible bleed lines. Of the four connections for these bleed lines, one was found fractured, another was attached, and a third contained recently fractured ends. The last connection was open, was intact, and did not contain any fragment of a pipe or a plug; these factors indicated that this bleed line was not connected at the time of the explosion.

A direct path from the intact open connection in the pilot vent stack to space No. 6CV could have existed only if a pilot valve were open in one of the pressure relief valves connected to the vent stack. Since the pressure relief valves were not disassembled, examination was limited, but there did not appear to be significant soot or other burned material in the intact open connection.

Hydrogen.--Caustic soda and zinc react to release hydrogen, a flammable diatomic gas. Hydrogen is flammable over a wide gas/air concentration range (4 percent to 75 percent). Hydrogen/air mixtures within these limits readily ignite when exposed to spark ignition sources. The minimum ignition energy required for a flammable

8/ A device designed to admit ambient air into a space where a vacuum has developed.

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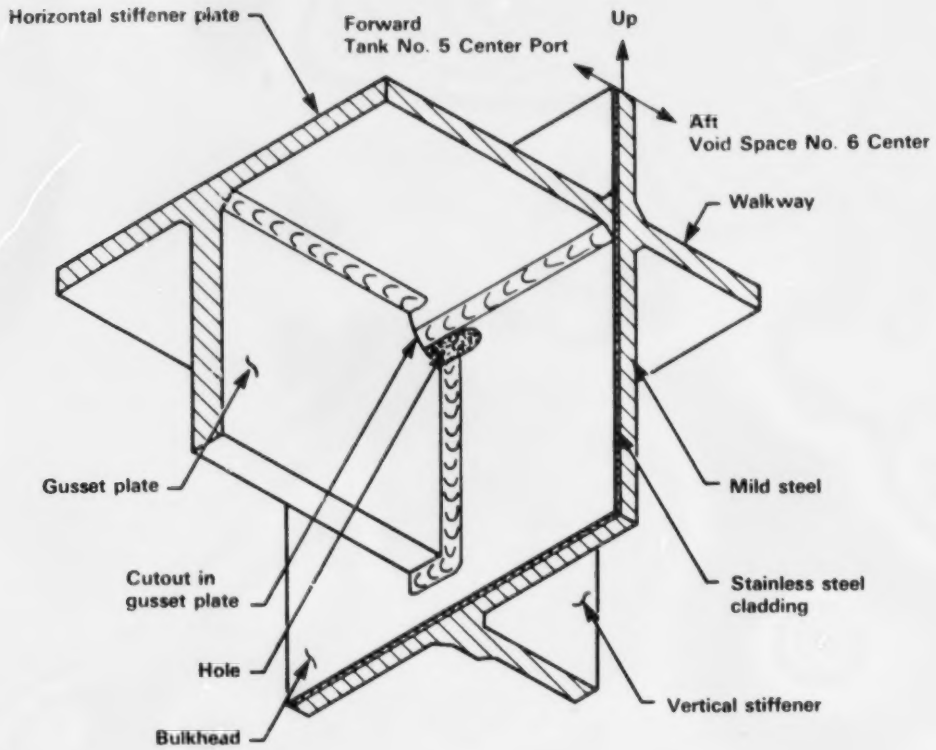

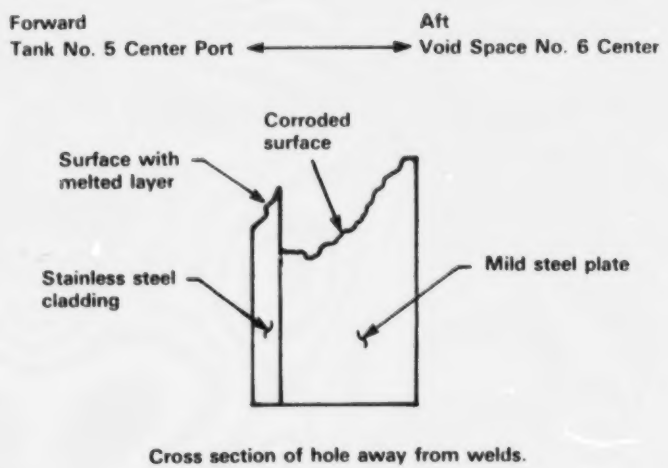

Cross section of hole away from welds.

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Figure 10.--Sketch of hole in bulkhead between tank No. 5CP and space No. 6CV as seen looking aft from inside tank No. 5CP and below the hole.

Figure 11.--Hole in the bulkhead between tank No. 5CP and space No. 6CV. (The horizontal stiffener plate and the gusset plate have been cut off.)

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hydrogen/air mixture is approximately 0.02 millijoule, as compared to approximately 0.25 millijoule required to ignite hydrocarbon vapor. Hydrogen/air mixtures burn rapidly and cleanly, leaving water vapor and no residue or soot. Ignition of hydrogen/air flammable mixtures in closed containers can produce significant pressure.

Other Information

Certificate of Inspection.--The PUERTO RICAN's Certificate of Inspection issued on June 22, 1984, designated the PUERTO RICAN as a "Chemical Carrier." The certificate authorized the vessel to carry the following cargo: "Grade 'B' and lower, other than oil; also specified dangerous cargoes (46 CFR Subchapter O Part 153)." Many of the cargos carried by the PUERTO RICAN were defined in 33 CFR 157.03 to be both oils 9/ and products, 10/ but none was crude oil. 11/ The certificate also authorized the carriage of vinyl chloride monomer (VCM) and butadiene (inhibited).

The restriction on the carriage of oil first appeared on a Certificate of Inspection amendment dated June 30, 1983. Title 46 CFR 32.53 requires an inert gas system (IGS) on vessels of 20,000 to 40,000 DWT that are crude oil tankers or are existing product carriers having high-capacity tank-washing machines. The USCG Marine Safety Information System (MSIS) indicates that the PUERTO RICAN was equipped with high-capacity tank-washing machines. However, the PUERTO RICAN was not equipped with high-capacity tank-washing machines. The PUERTO RICAN did not have an IGS system. Since the PUERTO RICAN did not have an IGS system and did not have high-capacity tank-washing machines, the Certificate of Inspection should have stated "other than crude oil" instead of "other than oil."

The USCG inspection for issuing this certificate was conducted during the PUERTO RICAN's May/June 1984 shipyard period. The USCG did not inspect the equipment necessary for the carriage of VCM. That equipment was in the following status:

- The submerged cargo pumps and associated electrical wiring had been removed in 1979;
- The nitrogen supply system was inoperative because the piping at the storage tank had been removed;
- The VCM cargo refrigeration system was inoperative and disconnected;
- The analyzer for the ARCUS Leak Detection System had been removed in March or April 1983, but the sampling lines in the cofferdams were not removed; and
- The liquid level alarm systems for space Nos. 3CV and 6CV were disconnected.

9/ "Oil" includes oil of any kind or in any form, including but not limited to petroleum, fuel oil, sludge, oil refuge, and oil mixed with wastes other than dredged spoil.
10/ "Product" means any liquid hydrocarbon mixture in any form, except crude oil, petrochemicals, and liquefied gases.
11/ "Crude Oil" means any liquid hydrocarbon mixture occurring naturally in the earth, whether or not treated to render it suitable for transportation, and includes crude oil from which certain distillate fractions may have been removed, and crude oil to which certain distillate fractions may have been added.

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After the PUERTO RICAN stopped carrying VCM and butadiene (inhibited), tank Nos. 3CP, 3CS, 6CP, and 6CS were made gas free, were inerted, and were never again used to carry any type of cargo. Since most of the equipment required to carry VCM and butadiene (inhibited) had been removed and the remainder had not been inspected, the Certificate of Inspection should not have listed these as cargoes permitted to be carried on the PUERTO RICAN. Since these cargoes were not being carried at the time of the explosion nor had they been carried since November 1979, the incorrect information on the certificate had no bearing on this accident.

USCG and ABS inspections.--During the May/June 1984 shipyard period, some of the cargo and ballast tanks were inspected by a USCG inspector and by an ABS surveyor. The USCG inspector relied on the ABS surveyor's records to keep track of the tanks inspected by the USCG and the ABS. The cargo tanks, including tank No. 5CP, were inspected with the aid of a bright light from convenient locations, such as the bottom of the tank or the tank ladder, which was normal tank inspection procedure. The USCG inspector and the ABS surveyor were aware that holes could develop in the stainless steel cladding. They found some holes, which were later repaired, and they considered the tanks to be in good overall condition. Even though a USCG inspector and an ABS surveyor are authorized to conduct an inspection in great detail, extraordinary measures that may cause undue expense or delay to the ship normally are not used unless there is reason to believe that a problem exists.

An ABS report dated May 10, 1984, indicated that the vessel was not currently carrying liquefied gases and that the Annual Hull Survey requirements for liquefied gases was to be carried out at the first liquefied gas loading port. The ABS owner's report dated November 1984 indicated that space Nos. 3CV and 6CV and tank Nos. 3CP, 3CS, 6CP, and 6CS were due for internal examination during November 1984.

Title 46 CFR 31.10-15(a) and (b) require an inspection before certification of a structure as suitable for carriage of a flammable and/or a combustible liquid. Title 46 CFR 38.25-1(a)(2) requires that an external examination of unlagged tanks and the visible parts of lagged tanks be made at each inspection for certification and at such other times as considered necessary for tank vessels carrying liquefied flammable gases.

Neither space Nos. 3CV nor 6CV was inspected by the USCG, the ABS, the owner, or the operator. They thought these spaces were inerted with nitrogen gas to inhibit corrosion. On May 14, 1984, a gas chemist entered space Nos. 3CV and 6CV when he certified the spaces to be "Safe for Workers - Not Safe For Hot Work." He further noted, "Ventilation recommended. Spaces are free of flammable gases and combustible liquids." Space Nos. 3CV and 6CV were not inerted following the gas chemist's certification. There are no regulations or requirements to inert space Nos. 3CV or 6CV.

Since tank Nos. 3C and 6C were authorized on the Certificate of Inspection to carry liquefied flammable gas cargos, technically they required an external inspection during the inspection for certification. The USCG inspector testified that space Nos. 3CV and 6CV were not inspected because he believed they were inerted and he was told that the sides of these areas were externally strengthened. Even if space Nos. 3CV and 6CV had been entered and inspected, the hole in the bulkhead between tank No. 5CP and space No. 6CV would not have been discovered because it had not yet penetrated the bulkhead.

Calculations performed by the Safety Board indicate that the amount of hydrogen generated in space No. 6CV was between approximately 4 percent and 10 percent of the volume of space around tank No. 6C, which was not occupied by liquid. The estimate of the amount of hydrogen included the following assumptions:

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1. The zinc completely reacted with the caustic soda;

2. Only pure air was lost or vented from the space;

3. The thickness of the zinc-rich epoxy on supports, restrainers, and stiffeners was the same as on the bulkheads;

4. All zinc in the epoxy coating involved was metallic zinc;

5. There was no sloshing; and

6. The 2,546 barrels of caustic soda corresponds to a 2-foot depth of caustic soda in space No. 6CV.

A model for predicting downwind concentrations of vented gases was developed by Southwest Research Institute for the USCG and was used to estimate the dispersion characteristics of hydrogen gas under extremely conservative conditions relative to the conditions on the PUERTO RICAN. The conditions assumed pure hydrogen and a 10 percent hydrogen/air mixture. The vent height of the model was 2 feet above the deck, and the two vent diameters were 3 inches and 6 inches. The vent volumetric flow rates ranged from 9.4 to 23.4 cubic feet per minute, and the wind speeds ranged from 1.25 to 5 mph.

For all cases examined, the concentration of vented gases fell below the lower flammable limit for hydrogen of 4 percent by volume in air, within approximately 2 feet downwind of the vent exit. The worst case, producing a 2-foot downwind flammable concentration, occurred for the highest vent volumetric flow rate of pure hydrogen and lowest wind speed. At wind speeds above 5 mph, no detectable flammable envelope existed.

Explosive force of hydrogen/air mixtures.--At the request of the Safety Board, the United States Department of the Interior, Bureau of Mines performed calculations to determine the explosion characteristics of mixtures of 5 percent H_2/95 percent air and 11 percent H_2/89 percent air. The results for a Chapman-Jouguet detonation 12/ and for an adiabatic-constant volume explosion are listed below. The initial condition of the H_2/air mixture assumed for the calculations was 20° C at 1 atmosphere of pressure (14.7 psia). The ideal gas law was assumed.

C-J detonation

	11% H_2	5% H_2
Detonation velocity, m/sec	1,337	986
Detonation pressure, atm	8.76 (128.8 psia)	5.13 (75.4 psia)
Detonation temperature, °K	1,607 (1,334° C)	961 (688° C)

Constant enthalpy/volume explosion

	11% H_2	5% H_2
Pressure, atm	4.6 (67.6 psia)	2.8 (41.2 psia)
Temperature, °K	1,429 (1,156° C)	844 (571° C)

12/ A fully developed, ideal detonation assuming complete reaction.

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Polybutene-24.--Polybutene-24 is a liquid polymer of isobutene. Chevron, U.S.A. Laboratory performed tests on a sample of the Polybutene-24 that had been loaded into tank No. 4PA. The specific gravity of this sample at 15° C (59° F) was 0.8974, and the flashpoint when tested by the Cleveland Open Cup method was 198.9° C (390° F). Polybutene-24 decomposes to produce isobutene when it is heated to about 250° C (482° F).

The temperature of the Polybutene-24 was monitored while aboard the ship by lowering a thermometer encased in a metal container to just below the surface of the Polybutene-24 for a minute or two before retrieving it to read the temperature. The metal container was designed to retain about an inch of cargo around the base of the thermometer. Another temperature reading was taken about halfway down into the cargo, and another temperature reading was taken near the bottom of the tank. However, records of temperatures were lost when the vessel sank. A former chief engineer stated that during the previous two voyages about the highest temperature they could attain with this cargo was 143° F, and that the temperature taken near the surface differed from the temperature taken near the bottom by about 15° F or 20° F.

Alkane-60.--Alkane-60 is a trade name for a mixture of Alkylbenzene liquid hydrocarbons. Chevron Research Company performed tests on a sample of Alkane-60 after it had been loaded into tank No. 5CP. The specific gravity at 15° C (59° F) was 0.8697. The flashpoint when tested by the Pensky-Martens Closed Cup method was 103.3° C (218° F).

Polybutene-24 and Alkane-60 testing.--PPG hired FaAA to analyze the cause of the explosion on the PUERTO RICAN. FaAA performed tests on three samples of Polybutene-24. Sample 1 was taken from shore tank No. 111 at Paktank in Richmond on February 5, 1985; sample 2 was taken from this same tank on March 4, 1985; and sample 3 was a portion of the sample taken when the vessel was loaded. These samples were tested and their flashpoints calculated. FaAA found that the flashpoint for sample 1 (160° F) was well below the value provided by Chevron (375° F) but that the flashpoints for samples 2 (370° F) and 3 (367° F) were very close to that specified. FaAA also determined that Alkane-60 could be ignited by a spark and that it would sustain combustion.

Ignition sources.--Ignition sources in space No. 6CV may have consisted of sparks from metal-to-metal impact of the galvanized piping against adjacent metal, from the movement of tank No. 6C, from the fracture of the weld connecting the longitudinal bulkhead between space No. 6CV and tank No. 4PA to the deck, or from electrostatic discharge.

Movement of Alkane-60 within space No. 6CV against the polyurethane insulation on tank No. 6C, or against the ship structure, and movement of the caustic soda with respect to the Alkane-60, resulting from the motion of the vessel, could have generated static electricity. Sloshing, splashing, or agitation of the Alkane-60 against itself also could have generated static electricity. Another potential source of static electricity was the flowing of Alkane-60 through the hole from tank No. 5CP down the polyurethane insulation on tank No. 6C. The amount of energy in an electrostatic discharge resulting from any of the above is unknown. Also, the level of energy in sparks caused by impact of the galvanized piping against adjacent metal or from movement of tank No. 6C is unknown.

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Potential ignition sources on deck were electrostatic discharges from the nylon flotation jacket worn by the pilot or from the polyester windbreaker worn by the third officer. Sparks from electrical equipment could have been another source of ignition, but the only electrical equipment on the foredeck known to be in use at the time of the explosion was the explosion-proof deck lighting. Sparks could have been generated from the metal-to-metal impact caused by the release of the plunger on the spring-loaded clip, but it is not known if the standby AB was unhooking the spring-loaded clip on the top chain from the railing at the time of the explosion. The amount of energy in sparks produced by these possible ignition sources is unknown.

Explosion scenarios.--FaAA postulated that the accident occurred as a result of a hydrocarbon fire in space No. 6CV, which slowly pressurized the void space and deposited combustion products on the underside of the deck. After the fire had been burning for at least several minutes, a pressure buildup could have caused the deck to bulge sufficiently to rupture the connection between the port longitudinal bulkhead and the deck in the area of tank No. 4PA. The contents of tank No. 4PA, Polybutene-24, would have been exposed directly to the fire in space No. 6CV, leading to a Polybutene-24 vapor explosion in tank No. 4PA, which could have thrown the pilot and crewmembers off the deck. The explosion in tank No. 4PA could have been followed shortly by the main area of the deck being thrown forward, primarily by a Polybutene-24 explosion in space No. 6CV and possibly also involving carbon monoxide formed by the prior combustion in space No. 6CV. According to FaAA, the most probable ignition source was a discharge of static electricity within space No. 6CV, generated by movement of Alkane-60 and caustic soda or by Alkane-60 moving against the polyurethane insulation and igniting either the hydrogen in the space first or the Alkane-60 directly.

Another possible scenario involves a hydrogen explosion in space No. 6CV, followed by ignition of Polybutene-24 and Alkane-60. Given that the deck weighed about 320 tons, a hydrogen explosion alone could have exerted sufficient force to invert the deck. As the hydrogen exploded, and the main deck was being lifted up, Polybutene-24 in tank No. 4PA could have vaporized and exploded, blowing Polybutene-24 and combustion products into space No. 6CV.

Another possible scenario involves overheating of the Polybutene-24 in tank No. 4PA by the heating coils at the bottom of the tank. Lack of stripping of lower molecular weight components of Polybutene-24 before it was shipped would have made it easier for vaporization to take place near the heating coils. If high vapor pressure developed near the heating coils and vented massively to the surface, causing overpressurization of the tank and tank/deck failure, the Polybutene-24 vapors then could have been ignited by a spark produced by the fracturing of the deck or from an ignition source on the deck. An explosion of the Polybutene-24 could have inverted the deck.

No evidence was found to indicate that the explosion might have been caused by sabotage or other union activities directed against the ship.

Pilot boat recovery system.--The equipment used by the pilot boat SAN FRANCISCO to recover the third officer and the pilot was specially designed and installed for the purpose of rescuing people from the water. The equipment consisted of a net, a small block and tackle, and a boom. (See figure 12.) The net was secured to the deck railing. A plastic pipe was secured to the center and another to the outboard edge of the net, and both pipes were parallel to the boat. These pipes helped to keep the net open and flat. Lines were secured to the forward and after ends of the net just outboard of the pipe in the center of the net. The crew could use these lines to pull the person in the net

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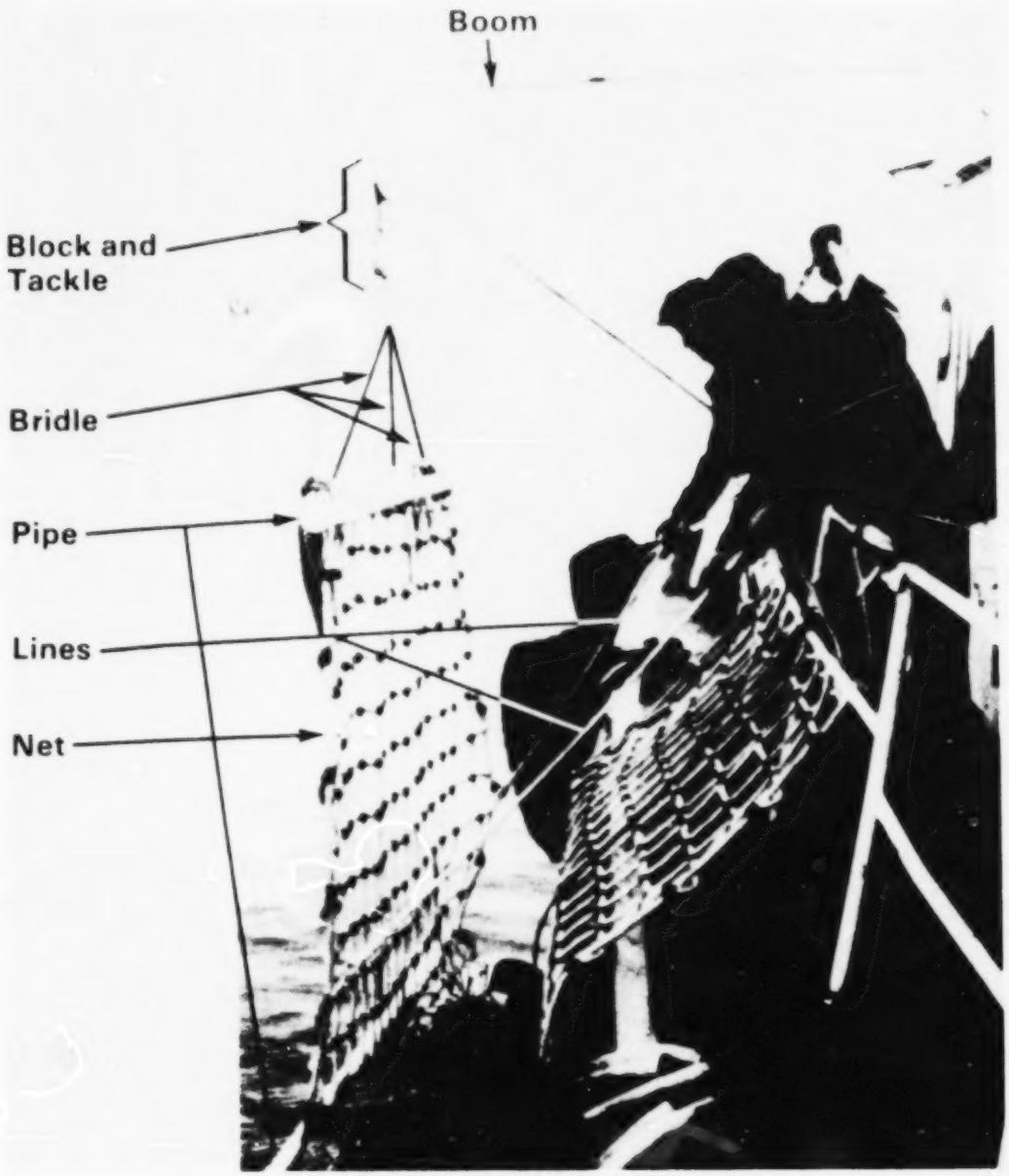

Figure 12.--Pilot boat recovery system.

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closer to the boat. The boom was stowed on top of the pilothouse and could be rigged easily to extend over the side of the vessel. The block and tackle was secured to the outboard end of the boom and to a bridle attached to the pipe on the outboard edge of the net.

The net was operated by lowering its outboard edge over the side of the boat and into the water. The boat was maneuvered so that the net could go under the person in the water, and the block and tackle was used to raise the net. The lines could be used to assist in raising the net and in frapping the net into the railing, which was inboard from the side of the vessel.

Station bill.--A safety consultant hired by Keystone conducted a safety inspection on board the PUERTO RICAN in August 1984. He testified that the station bill on the PUERTO RICAN, which the crew used for fire and boat drills, was an old-style station bill patterned after a Coast Guard CG-848 series form, which was developed during the 1940's. He had recommended to Keystone, after observing firefighting drills on the PUERTO RICAN, that a team concept of firefighting would be a more effective method of firefighting. At the time of the explosion, the station bill had not been revised.

Coast Guard Navigation and Vessel Inspection Circular (NVIC) No. 7-82, entitled "Sample Format of Vessel or Facility Station Bill," issued on April 13, 1982 (see figure 13), addresses problems in responding to fire, abandon ship, and other emergencies. The old station bill assigned each crewmember to specific firefighting stations, some of which might be unavailable or might not be needed to be manned, depending on the nature of the accident. The station bill format recommended by Coast Guard NVIC 7-82 differs from the old-style station bill in several ways. The new form has an easy-to-understand pictorial format that designates each crewmember to fire and boat emergency assignments. Each department is assigned special duties and duty stations. Each crewmember's assigned station is designated on the pictorial format by a symbol representing his department accompanied by a sequential number. A specific chain of command is designated within each department according to the crewmember's number on the station bill to prevent confusion as to who is in charge if a key person becomes disabled.

ANALYSIS

The Explosion

An explosion in an enclosed space requires the presence of flammable materials and a source of ignition. On the PUERTO RICAN, space No. 6CV contained Alkane-60 and hydrogen gas, which requires only one-twelveth as much energy to ignite as hydrocarbon vapors. Although the exact amount of hydrogen present in space No. 6CV could not be determined, calculations indicate that the hydrogen content in space No. 6CV probably was above the lower flammable limit.

On-deck ignition of hydrogen is unlikely since the hydrogen dispersion tests indicated that the ignition source would need to be close to an opening in space No. 6CV to have sufficient hydrogen to ignite. All of the on-deck ignition sources were too far from the possible openings in space No. 6CV to have ignited flammable vapors flowing through them.

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U.S. Department of Transportation
United States Coast Guard

Station Bill

Sample Format Only

General Instructions

1. EACH person shall familiarize themselves with their assigned location in the event of an emergency immediately upon boarding the vessel.

2. All crew members shall be thoroughly familiar with the duties they are assigned to perform in the event of an emergency.

3. Each person shall participate in emergency drills and shall be properly dressed including a properly donned life preserver or exposure suit.

4. In all vessels carrying passengers, the STEWARD'S DEPARTMENT shall be responsible for warning passengers, seeing that passengers are properly dressed and have correctly donned their life preservers or exposure suits, assembling and directing passengers to their appointed stations, keeping order in passageways and stairways, controlling passenger movements and ensuring a supply of blankets is taken to the lifeboats.

5. The proper chain of command is indicated by the sequential numbers assigned to each department. Should a key person become disabled, the next senior member of that department shall take the disabled person's place.

6. The Chief Mate shall be responsible for the maintenance and readiness of all lifesaving and firefighting appliances and equipment above the main deck. The First Assistant Engineer shall be responsible for the maintenance and readiness of all lifesaving and firefighting appliances and equipment on the main deck and below.

MASTER'S SIGNATURE

Fire and Emergency

Instructions

1. ANY person discovering a fire shall notify the bridge by sounding the nearest available alarm and then take all initial actions as appropriate.

2. Upon hearing the fire and emergency signal all airports, watertight doors, fire doors, scuppers, and designated discharges shall be closed and all fans, blowers and ventilating systems shall be stopped. All safety equipment will be prepared for immediate service. OMED's Numbers 9 and 10 shall check to ensure this item is completed after they report to their station.

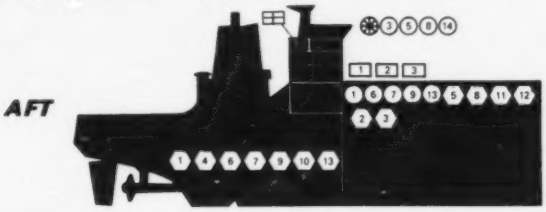
3. Upon seeing a "MAN OVERBOARD", immediately throw a life preserver (with a light attached if at night) and notify the bridge by reporting "MAN OVERBOARD PORT (STARBOARD) SIDE". In all cases keep the man in sight.

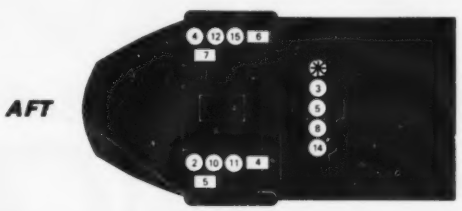
4. Any extra persons shall report to the Hospital Treatment Room.

Signals

Fire and Emergency Signal (———)
The fire and emergency signal shall be a continuous blast of the whistle for a period not less than 10 seconds followed by a continuous ringing of the general alarm for not less than 10 seconds.

Man Overboard Signal (– – –)
The man overboard signal shall be the letter "O" sounded several (at least 4) times on the ship's whistle followed by the same signal on the general alarm.





Abandon Ship

Instructions

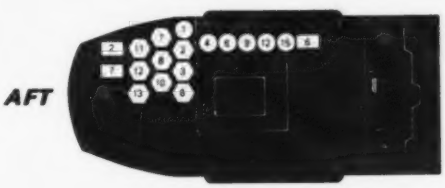
1. All persons indicated in the diagram on the left should use lifeboat #2. All persons indicated in the diagram on the right should use lifeboat #1.

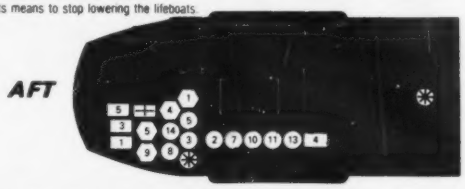
2. Any extra persons should muster at lifeboat #1.

Signals

Abandon Ship Signal (– – – – – ———)
The abandon ship signal shall be at least 7 short blasts followed by one long blast on the ship's whistle followed by the same signal sounded on the general alarm.

Boat Handling Signals
All boat handling signals shall be sounded on the ship's whistle and shall mean the following:
(-) One short blast means to lower the lifeboats.
(- -) Two short blasts means to stop lowering the lifeboats.





Personnel and Duties

Deck Department Functions

Symbol	Position	Fire & Emergency	Abandon Ship	Symbol	Position	Fire & Emergency	Abandon Ship
	MASTER	In Command	In Command Lifeboat No. 1		Quartermaster	Helmsman	Assist as Directed
	Chief Mate	In Charge * Emerg. Squad	In Command Lifeboat No. 2		Quartermaster	Emerg. Squad	Man Frapping Lines No. 2
	Second Mate	In Charge STBD Boatdeck	In Charge Lowering No. 1		Able Seaman	Boat Detail STBD Boatdeck	Man Frapping Lines No. 1
	Third Mate	Assist Master	Provide Nav. Equip.		Able Seaman	Boat Detail STBD Boatdeck	Man Frapping Lines No. 1
	Third Mate	In Charge Port Boatdeck	In Charge Lowering No. 2		Able Seaman	Boat Detail Port Boatdeck	Man Frapping Lines No. 2
	Deck Cadet	Assist as Directed	Assist as Directed		Ordinary Seaman	Emerg. Squad	Lower Ladder Tend Sea Pntr
	Boatswain	Emerg. Squad	Operate Winch No. 2		Ordinary Seaman	Messenger	Launch Liferaft No. 1
	Quartermaster	Emerg. Squad	Operate Winch No. 1		Ordinary Seaman	Boat Detail Port Boatdeck	Lower Ladder Tend Sea Pntr

* The Chief Mate is in charge of the Emergency Squad if the Emergency is outside the engine spaces

** The First Assistant Engineer is in charge of the Emergency Squad if the Emergency is in the engine spaces

NOTE: The distress signal from all Emergency Stations shall be 3 short blasts of the ship's whistle (· · ·)

Engineering Department Functions

Symbol	Position	Fire & Emergency	Abandon Ship	Symbol	Position	Fire & Emergency	Abandon Ship
	Chief Engineer	In Charge Engineroom	Boat Engineer No. 1		OMED	Emergency Squad	Launch Liferaft No. 2
	First Assist Engineer	In Charge ** Emerg. Squad	Boat Engineer No. 2		OMED	Engineroom Assist	Launch Liferaft No. 1
	Second Assist Engineer	Emergency Squad	Assist Boat Engineer No. 2		OMED	Engineroom Assist	Assist as Directed
	Third Assist Engineer	Engineroom Assist	Assist Boat Engineer No. 1		OMED	Emergency Squad	Assist as Directed
	Third Assist Engineer	Emergency Squad	Assist as Directed		Wiper	Emergency Squad	Launch Liferaft No. 2
	Third Assist Engineer	Engineroom Assist	Assist as Directed		Wiper	Engineroom Assist	Assist as Directed
	Engine Cadet	Engineroom Assist	Assist as Directed				

Steward's Department Functions

Radio Officer	At Radio Station	Provide Emerg. Radio	General Steward Util	Boat Detail STBD Boatdeck	Assist as Directed
Chief Steward	In Charge Hosp. Treat. Rm.	Assist Extra Pers. Boat No. 1	General Steward Util	Boat Detail STBD Boatdeck	Assist as Directed
Chief Cook	Assist in Hosp. Treat. Rm.	Assist Extra Pers. Boat No. 2	General Steward Util	Boat Detail Port Boatdeck	Assist as Directed
General Steward Util	Assist in Hosp. Treat. Rm.	Provide Blankets & First Aid Kit	General Steward Util	Boat Detail Port Boatdeck	Provide Blankets & First Aid Kit

Figure 13.--Sample format of vessel or facility station bill.

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A source of ignition within space No. 6CV could have been a spark generated by the impact of tank No. 6C against the antiflotation chocks, caused by motion of the vessel, if the "Marinite-65" slats were missing or if the sugar maple wood under the tank were destroyed. Another source of ignition in space No. 6CV could have been a spark generated by metal-to-metal impact between the galvanized piping system and its support brackets. One side of a bracket supporting the piping in the top of space No. 6CV was found not bolted and was hanging loose. Another source of ignition within space No. 6CV could have been electrostatic charge buildup and spark discharge caused by the movement of conductors and nonconductors--caustic soda, Alkane-60, and the polyurethane insulation--against one another. Although the amount of energy in sparks produced by these methods is unknown, these sources of ignition cannot be discounted.

If the percentage of hydrogen in space No. 6CV were less than 4 percent and if the Alkane-60 had been ignited, the pressure buildup in space No. 6CV from a fire would not have been a slow process as postulated by FaAA. The presence of Alkane-60 and polyurethane insulation would have led quickly to a vigorous fire. Also, space No. 6CV had four pressure relief valves set at 2, 2.6, 2.8, and 3.0 psig, which would have been relieving for some time had there been a slow buildup of pressure. Since the sound that may have been a relief valve operating was not heard until 1 or 2 seconds before the explosion, the pressure in space No. 6CV obviously increased rapidly from the 2 psig required to actuate the relief valve to the pressure required to fracture the deck. Therefore, it is unlikely that the bulkhead between space No. 6CV and tank No. 4PA separated from the deck as a result of a gradual buildup of pressure in space No. 6CV, or that a hydrocarbon fire existed in space No. 6CV for any significant length of time before the explosion.

Tank No. 4PA was a deep tank with a narrow cross sectional area. The narrow tank configuration might have limited the convection activity of the heated Polybutene-24, and might have allowed a massive vapor bubble to accumulate near the heating coils if the Polybutene-24 was overheated and had not been stripped of low molecular weight components. This massive vapor bubble might have vented to the surface and ruptured tank No. 4PA and the deck. The Polybutene-24 vapor and hydrogen could have been ignited by a spark caused by the fracturing of the deck. While the FaAA's tests indicate that one sample of Polybutene-24 had a flashpoint of only 160° F, the other two samples were close to the published values. The Polybutene-24 which was aboard the PUERTO RICAN at the time of the explosion was tested to have a flashpoint of 390° F, which indicates that the low molecular weight fractions had been removed. Although the Polybutene-24 would have begun to decompose to flammable isobutene at temperatures approaching 480° F, it is unlikely that the temperature of the steam in the heating coils significantly exceeded 300° F. There was a 10° to 15° F steam temperature drop between the engineroom and heating coils, and the chief engineer said that he limited the pressure of the saturated steam leaving the engineroom to 70 psig, for a temperature of 316° F. The ship service steam had a pressure of 120 psig and a temperature of 350° F, a pressure relief valve was set at 140 psig (360° F), and there were high-pressure and high-temperature alarms. Since neither the pressure relief valve nor either of the alarms activated, it is highly unlikely that the steam temperature in the heating coils could have exceeded 340° F even if the globe valve to the heating coils was wide open. Accordingly, it is unlikely that the saturated steam entering the heating coil system from the engineroom could have caused the Polybutene-24 to vaporize or decompose. Therefore, the Safety Board believes that the explosion did not result from the overheating and vaporization or decomposition of Polybutene-24.

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If the percentage of hydrogen in space No. 6CV were greater than 4 percent and if the hydrogen had been ignited, the atmosphere in that space would have exploded. Calculations indicate that there was a flammable concentration of hydrogen in space No. 6CV, and that the force of a hydrogen explosion would have been sufficient to lift and invert the deck. The Alkane-60 in space No. 6CV would have been ignited by the hydrogen explosion, and Alkane-60 combustion deposits would have been found in space No. 6CV and on the underside of the deck. As the hydrogen exploded and the main deck was being lifted up, the Polybutene-24 in tank No. 4PA would have ignited and could have exploded. Either the hydrogen explosion or a Polybutene-24 explosion would have blown Polybutene-24 and its combustion products into space No. 6CV. Flammable hydrogen air/mixtures require only a small amount of energy to be ignited, a quantity that easily could have been provided by an electrostatic discharge or forceful metal-to-metal impact. Therefore, the Safety Board believes that the weight of the available evidence indicates that the most likely cause of the explosion on board the PUERTO RICAN was the ignition of flammable hydrogen gas in space No. 6CV.

Metallurgical Factors

The fact that the previously molten stainless steel metal on the tip of the lip of stainless steel cladding at the edge of the hole in the bulkhead between tank No. 5CP and space No. 6CV was not weld material indicates that the hole probably resulted from a gouge at the surface of the stainless steel due to an incomplete weld or from arc cutting of the stainless steel cladding. The missing cladding allowed caustic soda to react with and corrode the underlying mild steel bulkhead that it was supposed to protect. The caustic soda and mild steel reacted and corroded until a hole was eaten through the after bulkhead in tank No. 5CP to space No. 6CV. Since there was no evidence of any repairs having been made in the vicinity of the holes, the incomplete weld or arc cutting probably was done during the original fabrication of the tank, which took place about 1970 or 1971, instead of during more recent repairs.

The lip that the stainless steel cladding formed on the tank No. 5CP side of the mild steel bulkhead formed a pocket, which probably held the rust and prevented it from dripping onto the stainless steel cladding where the rust stain would have been noticed. Retention of this rust material by the stainless steel clad lip on the tank No. 5CP side of the pit and the remote and obscure location of the hole is the most probable reason that the pit was not discovered during inspections.

Cargo Leakage

The hole in the bulkhead between tank No. 5CP and space No. 6CV was large enough so that the 2,546 barrels of caustic soda missing from tank No. 5CP could have leaked into space No. 6CV in the approximately 15 days the vessel traveled from Lake Charles to San Pedro. Calculations indicate that an estimated 1,100 barrels of Alkane-60 passed through the hole during the approximately 2.4 days from the time it was loaded in Richmond until the explosion. (See figure 14.)

The efforts of the master, chief officer, and pumpman in checking all adjacent cargo tanks and in sounding all void spaces and double bottoms surrounding tank No. 5CP (except space No. 6CV) for the missing caustic soda were not insignificant. However, the master made no further effort to inspect space No. 6CV after unsuccessfully attempting to locate a sounding tube. Even though he believed that space No. 6CV had been inerted, there were other alternatives available. For example, the master could have requested assistance by telephone from Keystone's home office. If he had done so, it is possible that

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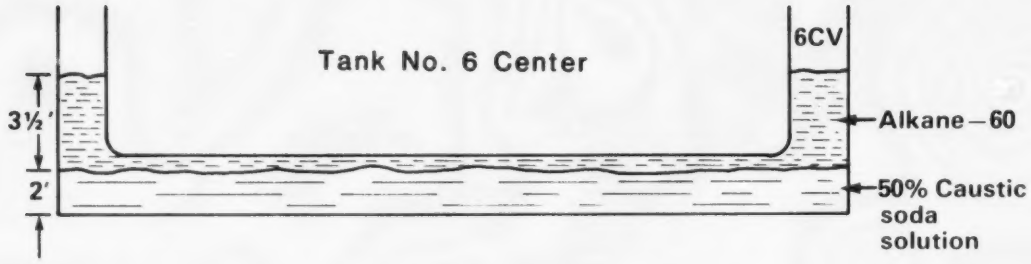

Figure 14.--Schematic showing 50 percent caustic soda solution and Alkane-60 in space No. 6CV shortly before the accident.

he would have discovered that space No. 6CV had not been inerted, since a gas chemist had certified the space as "safe for workers" during the May/June 1984 shipyard period. He also might have been informed of the existence of the eductor system in space No. 6CV. In any event, after the PPG loading figures and the ship's loading figures had been compared and the tanks, void spaces (except No. 6CV), and double bottoms surrounding tank No. 5CP had been checked, only two explanations for the apparent cargo shortage remained--either the discharge ullage was incorrect or caustic soda had leaked into space No. 6CV. Since there was no way at that time to conclusively determine the accuracy of the discharge ullage, the master should have made additional efforts to inspect space No. 6CV to resolve the uncertainty.

Since space No. 6CV was not inerted, it could have been entered and inspected. If space No. 6CV had been inspected, caustic soda would have been discovered. That discovery probably would have led to discovery and repair of the hole as well as removal of the caustic soda. With the hole repaired and the caustic soda removed from space No. 6CV, any part that the Alkane-60 or the hydrogen may have played in the explosion would have been eliminated. If the master had required that space No. 6CV be inspected for the presence of caustic soda, the accident might have been prevented.

Survival Aspects

Since the third officer and the pilot were both severely burned and the pilot had serious leg injuries, the rescue capabilities of the pilot boat SAN FRANCISCO played a vital role in their prompt rescue. The use of the recovery system nets enabled the pilot boat crew to minimize or eliminate several obstacles that otherwise would prevent a successful rescue in many cases. For example, the height of the deck of a vessel above the water often makes it impossible for a rescuer to reach over the side and grab the person being rescued. Since the deck at the stern of a vessel is usually the closest to the water, a rescue boat may be tempted to approach the person in the water stern-first. Such an approach is dangerous since the person being rescued may be drawn into the propeller by the propeller wash or otherwise injured by the propeller. A stern approach on some vessels, such as the pilot boat SAN FRANCISCO, is even more difficult since the operator cannot see the stern as he maneuvers the boat. The added weight of wet

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clothing on a person being pulled from the water adds to the difficulty of lifting a person aboard. The urgency of an expeditious rescue is intensified when the person being rescued is weak, injured, unconscious, or hypothermic and unable to assist in the rescue.

The recovery system nets aboard the pilot boat considerably reduced most of the rescue difficulties. The recovery nets were located on both sides of the pilot boat, which facilitated maneuvering the boat so the rescue net could be brought to the person being rescued. This system eliminated the danger of having to rescue the person near the propeller. Since the block and tackle and boom could be easily and quickly rigged, and the net was already stowed rolled up alongside the boat where it could be readily released, the delays in rescue were considerably reduced. An expeditious rescue was facilitated because the net could be maneuvered under the person in the water. The difficulty of lifting a person with the added weight of wet clothing can be facilitated by using the block and tackle.

The recovery net, which was designed specifically for use on the pilot boat SAN FRANCISCO, operates similarly to rescue equipment used on both land and water by law enforcement agencies, the Navy, and the USCG. Several brands and sizes of such rescue equipment are available commercially as off-the-shelf products. However, despite their relatively low cost (generally under $1,000), these devices do not appear to be in wide use in the marine industry.

Because of the important role that the recovery system on the pilot boat SAN FRANCISCO played in the rescue of the third officer and the pilot, and the many obstacles to a rapid rescue that use of the recovery system eliminated, the Safety Board encourages the use of this type of equipment on rescue or other type of watercraft.

A float-free, self-releasing liferaft is designed to float free and release only after a vessel has sunk. However, there are instances, such as in this accident, where manual launching of the liferaft may be desired. The stern of the PUERTO RICAN had not sunk when the crew wanted the liferaft launched, so they manually lifted, with much difficulty, the 400-pound liferaft over the 42-inch-high railing. A removable section in the railing near the liferaft would have facilitated the launching.

Since the explosion of the PUERTO RICAN occurred close to San Francisco, enabling the use of VHF-FM radio for communication with USCG San Francisco and nearby boats and aircraft, coordination of emergency response from other boats and aircraft was simplified. If the accident had occurred beyond the relatively short VHF-FM radio range, an emergency response might have been delayed because the explosion destroyed the PUERTO RICAN's long-range radio antennas, which extended from the deckhouse to the kingposts located on the deck that was inverted by the explosion. Since the fire prevented another antenna from being installed in the same location, the Safety Board believes that an easy-to-rig spare antenna should be available on vessels that do not have another long-range radio antenna and on vessels that have antennas extending over locations such as cargo tanks where they might be destroyed by explosions. The antenna should be designed to be rigged in a location different from the original antenna in case the original location is damaged.

Although implementation of the station bill as recommended by Coast Guard NVIC No. 7-82 probably would not have affected the outcome in this accident, this method of organizing firefighting, abandon ship, and emergency efforts is superior to that in the old station bill because the new pictorial format is easier to understand, and because a team concept assigns each department specific duties in addition to the specific assignments

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assigned to individuals. The team concept has the flexibility to address changing emergency conditions. The new station bill format is also better because a specific chain of command is designated within each department according to the crewmember's number on the station bill to prevent confusion as to who is in charge if a key person is unavailable.

During the emergency response after the explosion, the master was moving about the stern of the ship instead of staying on the bridge which is his normal emergency fire and boat station. Because of the recent changes in the crew and the nature of the emergency, this action was appropriate. Although he was trying to respond to critical problems, he did not coordinate the action of the crewmembers and control the overall emergency response. He and his officers did not use their portable transceivers for communication. The master designated the second officer to take charge of the deck but never communicated with him during the rest of the emergency. The master never gave an order to actually launch the lifeboats and the liferaft, but the lifeboats and the liferaft were launched under the direction of the second officer. Also, a muster of the crew was not taken. Contrary to normal practice in the industry, the master was not directly involved with the emergency efforts being made by those not aboard the PUERTO RICAN, with the exception of the few brief times that he spoke on the radio from the bridge.

Even though a considerable firefighting effort was made by the master and several of the officers and crewmembers, the master and deck officers should have used their portable transceivers for onboard communications. By using portable transceivers, the second officer could have informed the master of his concern that the vessel was taking a list that might hinder launching lifeboats. Also, the second officer could have informed the master that he was abandoning ship with the crewmembers. The third officer on the bridge could have informed the master of information she received about the status of lifesaving and firefighting activities occurring from resources other than on the ship. With this information, the master could have been involved in decisions being made by other officers aboard the PUERTO RICAN as he attempted to repair the damaged firefighting system.

Foam is used to extinguish the type of fire that existed on the liquid in space No. 6CV and the adjacent wing tanks. A layer of foam floats on the burning liquid surface and smothers the fire by cutting off oxygen. Since foam and water were being applied to the fire in space No. 6CV and the adjacent wing tanks, the water would have broken up the blanket of foam and reduced its fire-extinguishing qualities.

Vessel Inspection and Certification

Although standard tank inspection procedures using a bright light from convenient locations were used, the inspections of the PUERTO RICAN made by the USCG and the ABS during its May/June 1984 shipyard period did not reveal the pit in the tank No. 5CP side of the bulkhead, which later developed into a hole penetrating to space No. 6CV. A pit and not a hole existed at the time of the inspection because no loss of cargo carried in tank No. 5CP was experienced until the loss of caustic soda on the voyage before the explosion. The pit probably was not located during the many inspections since the tank was constructed because of its remote and obscure location. The lip around the pit formed by the stainless steel cladding in tank No. 5CP probably prevented rust from leaking onto the shiny stainless steel cladding where it could have been more easily seen. The pit would not have been discovered during the May/June 1984 USCG and ABS inspections even if space No. 6CV had been inspected, since the pit had not yet penetrated to space No. 6CV.

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Although Keystone had not requested the USCG to inspect the heating coils installed during the May/June 1984 shipyard period, the USCG should have become aware of the heating coil installation due to its activities during the USCG inspection in the shipyard. Even though the heating coils were not inspected by the USCG, the heating coils were inspected by a private contractor and tested under 200 psig of water pressure, as is normally done during USCG inspections, and found to be in good condition.

CONCLUSIONS

Findings

1. The hole in the bulkhead between cargo tank No. 5CP and space No. 6CV existed before the accident. The hole resulted from a gouge in the stainless steel cladding, which probably resulted from improper welding when the tank was constructed. The gouge exposed the mild steel behind it to the caustic soda, which corroded the mild steel until a hole later developed through the bulkhead.

2. The caustic soda in cargo tank No. 5CP leaked into space No. 6CV and reacted with the zinc in the bulkhead and deck coatings and on the galvanized piping. The chemical reaction produced hydrogen gas.

3. The caustic soda in space No. 6CV would have been found if space No. 6CV had been inspected following notification that the loading ullage in tank No. 5CP differed from the predischarge ullage.

4. During the May/June 1984 shipyard period, Coast Guard and American Bureau of Shipping inspectors did not make a detailed inspection of areas of the tank that were not relatively easy to inspect from convenient locations because the general condition of tank No. 5CP appeared to be good.

5. There is no evidence that the explosion was the result of sabotage.

6. The reason that samples of Polybutene-24 had different flashpoints is unknown.

7. The incorrect cargo authorizations and other erroneous information on the vessel's Certificate of Inspection had no bearing on the accident.

8. The firefighting effectiveness of the application of foam to the fire in space No. 6CV and the adjacent wing tanks was decreased by the simultaneous application of foam with water from fire hoses.

9. The pilot boat recovery system on the pilot boat SAN FRANCISCO provided a suitable means for recovering helpless persons from the water.

10. Launching of the float-free, self-releasing liferaft would have been easier and faster if the PUERTO RICAN had had removable rails.

11. The loss of the long-range radio antenna did not prevent communications between the vessel and shore facilities because the proximity of the vessel to shore stations permitted use of the VHF-FM radio, but if the vessel had been beyond the range of the VHF-FM radio, the vessel would have been unable to communicate by radio with those shore stations.

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Probable Cause

The National Transportation Safety Board determines that the probable cause of the explosion on board the tankship PUERTO RICAN was the master's failure to require that center void space No. 6 be inspected for the presence of 50 percent caustic soda solution when he became aware of the possibility of a cargo leak from center port cargo tank No. 5. Flammable hydrogen gas produced by the reaction of the caustic soda solution with zinc in the epoxy paint and in the galvanized piping in center void space No. 6 was ignited by an undetermined source.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board made the following recommendations:

--to the United States Coast Guard:

Publicize throughout the marine industry the availability and benefits of the use of rescue equipment similar to the recovery system used on the pilot boat SAN FRANCISCO. (Class II, Priority Action) (M-86-33)

Require liferafts to be installed so that unnecessary lifting, such as over railings, will not be required when they are manually launched. (Class II, Priority Action) (M-86-34)

--to the Keystone Shipping Company:

Establish procedures to require the sounding or inspection of all underdeck spaces when ullage readings or other measurements indicate that cargo may have leaked from any tank. (Class II, Priority Action) (M-86-35)

Revise station bills as recommended by United States Coast Guard Navigation and Vessel Inspection Circular No. 7-82. (Class II, Priority Action) (M-86-36)

--to the Federal Communications Commission:

Require a simple-to-install spare radio antenna on oil and product tankers whose radio antennas extend over cargo tanks where they are vulnerable to damage from an explosion or fire. (Class II, Priority Action) (M-86-37)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JIM BURNETT
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ JOHN K. LAUBER
Member

/s/ JOSEPH T. NALL
Member

April 18, 1986

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APPENDIX

CREW INFORMATION

Master James C. Spillane

James C. Spillane graduated from the State University of New York Maritime College at Fort Schuyler in 1969. He had been licensed as "Master, Steam and Motor Vessels of Any Gross Tons Upon Oceans" for about 5 years. Previously, he served as a licensed deck officer on numerous tankships, including several chemical carriers. Mr. Spillane had reported on board the PUERTO RICAN in September 1984 and had served as chief officer until October 30, 1984, when he relieved the previous master.

Previous Master Kazimierz Z. Wodka

Kazimierz Z. Wodka graduated from the State University of New York Maritime College at Fort Schuyler in 1965. He was licensed as "Master, Steam and Motor Vessels of Any Gross Tons Upon Oceans." Previously, he had served as a licensed deck officer on several chemical carriers during his 19-year employment with Keystone Shipping Company. Mr. Wodka served as permanent master on a T-5 chemical tankship from 1976 to 1984. He was assigned as master of the PUERTO RICAN on August 21, 1984.

Chief Officer Norton J. Gelb

Norton J. Gelb had been hired as chief officer by Keystone Shipping Company to replace Mr. Spillane, who had been assigned as master. Mr. Gelb reported on board the PUERTO RICAN about 2200 on October 30, 1984.

Second Officer Constantinos Vafiades

Constantinos Vafiades had more than 25 years' experience on merchant vessels, including 16 1/2 years as third officer. He joined the PUERTO RICAN as a third officer on October 22, 1984. He was assigned as the second officer when the previous second officer departed from the vessel on October 30, 1984.

Third Officer Debra K. Cobb

Debra Cobb graduated from Texas Maritime College at Galveston, Texas, in May 1984. She joined the PUERTO RICAN on October 6, 1984, at Nederland, Texas. Miss Cobb had not sailed as a licensed deck officer before reporting on board the PUERTO RICAN.

Third Officer Philip R. Lampriere

Philip R. Lampriere graduated from the U.S. Merchant Marine Academy in June 1984. He reported on board the PUERTO RICAN as third officer about 2200 on October 30, 1984, to replace Mr. Vafiades. Mr. Lampriere had not sailed as a licensed deck officer before reporting on board the PUERTO RICAN.

Chief Engineer Charles R. Kalmbach

Charles R. Kalmbach had about 40 years' experience at sea in the engineering department, including about 34 years as a licensed engineering officer. He had obtained his license as chief engineer in 1969. Mr. Kalmback had sailed on board the PUERTO RICAN for about 5 1/2 years.

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